Technical Report 1229

Training to Operate a Simulated Micro-Unmanned Aerial Vehicle with Continuous or Discrete Manual Control

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14. ABSTRACT *(Maximum 200 words)*:

This report investigates the effects of continuous vs. discrete control methods and the number of simultaneous camera views on operator performance during training to manually control a simulated micro-unmanned aerial vehicle (MAV). Seventy-two participants were trained to operate a MAV in a simulated environment, to designated criterion levels. They were then given training missions during which performance was measured. Eight conditions were investigated, formed by crossing three 2-level factors: input device (mouse vs. game controller), input control display (discrete vs. continuous), and number of simultaneous camera views (one vs. two). Superior performance was observed when a continuous input method (e.g., multiple degrees of freedom) was provided for continuous MAV functions (e.g. maneuvering in space) and a discrete input method (e.g., single action) was provided for discrete MAV functions (e.g., command to hover). Under these conditions, mission times were shorter, collisions were fewer, and more targets were photographed. Effects of video game experience and spatial ability were also investigated. Recommendations for the design of unmanned vehicle controls were discussed.

15. SUBJECT TERMS

Spatial ability, video game, user-interface, remote control, robot

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TRAINING TO OPERATE A SIMULATED MICRO-UNMANNED AERIAL VEHICLE WITH CONTINUOUS OR DISCRETE MANUAL CONTROL

EXECUTIVE SUMMARY

Research Requirement:

Unmanned systems are envisioned to be a key part of the Army's future force. At the platoon level, Soldiers will have the Class I unmanned aviation system, as well as unmanned ground sensor systems. The Class I will support reconnaissance, surveillance, and target acquisition. Able to take-off and land vertically like a helicopter, the system will be small enough to be carried in the field by dismounted infantry Soldiers. Ideally, the Class I will be relatively easy to operate, enabling rapid training and dispensing with the need for specialized, dedicated operators (Office of the Secretary of Defense, 2002).

The need to quickly and reliably train Class I operators requires that the human-system interface be intuitive and easy to master. Moreover, structured training must be developed to ensure that training is efficient and effective. Despite this, little attention has been devoted to user interface design or training development. The purpose of this research was to redress some of these gaps by examining the effect of user interface design during training to pilot a simulated micro-unmanned aerial vehicle (MAV) in manual mode.

Procedure:

Seventy-two participants were trained to operate a MAV in a simulated environment. Initial training involved familiarization with the user interface and practice exercises. During the practice exercises, operators had to conduct a sequence of written or oral instructions within a set period of time. They then had to navigate the MAV around two different flight skill tracks. They were given five attempts to complete these tracks within a designated amount of time and without any collisions. Operators were then given a series of training missions during which their performance was measured. Repetition of the flight skill courses allowed for an assessment of performance improvement during the course of training; during these repetitions performance measures included time-to-complete, number of collisions, and subjective workload. There were also two more tactical missions in which target detection was required. During these missions measures included number of targets detected, number of collisions, and subjective workload.

Each operator participated in one of eight conditions, with the conditions determined by the user interface configuration. The eight conditions were formed by crossing three 2-level factors: input device (mouse vs. game controller), input control display (discrete vs. continuous), and number of simultaneous camera views (one vs. two). Regarding the input device, a mouse was used as a surrogate for touch screen technology. Many operator control unit (OCUs) utilize touch-screens; however touch inputs register less reliably than mouse inputs. Consequently, we used a mouse to better equate input reliability across input devices. The alternate input device was a game controller. Game controllers are used to control movement of virtual characters in virtual environments, analogous to how a MAV operator must control the movement of the

MAV using sensor imagery from the MAV's cameras. It therefore, seemed like a natural input device for this task. The mouse (or any point-and-click method) represents a discrete method on input, in that one and only one command can be given at a time. The game controller represents a continuous method of input, in that continuous adjustments of the thumb sticks on the game controller (see Figure 3) translate into continuous adjustments in MAV flight. The second factor manipulated (input control display) involved how the input controls were displayed on OCU screen (see Figures 1 and 2). In one version, the display was discrete in that specific symbols represented specific maneuvers (e.g., an up-pointing arrow represented upward movement, and a down-pointing arrow represented downward movement). In the alternate version, the display was continuous in that display elements could be manipulated along a continuum (e.g., the location of a dot relative to a home position could be moved up or down to control altitude). The third factor was number of simultaneous camera views. Typical OCUs only display sensor imagery from one camera at a time. In this study we examined whether providing both camera views at the same time would provide any advantage in maneuvering the MAV and avoiding collisions.

Findings:

Performance improved over the repetitions of the flight skills tracks, suggesting that participants had learned something during training. It was not possible to distinguish the relative contributions of skill mastery vs. spatial learning to this improvement because all missions were run in the same simulated environment. Video game experience and spatial ability correlated with measures of performance.

Performance was better when there was a better match between the continuity of the control method and the continuity of the function to be controlled. When maneuvering the MAV in 3-D space, participants did better with the continuous methods. Mission times were shorter, collisions were fewer, and more targets were photographed. For example, for participants using the mouse, the continuous control interface supported faster mission completion, compared with the discrete control interface. In the former case, participants were able to control maneuver in different dimensions simultaneously, whereas in the latter, maneuvers in only one dimension could be input at a time. In contrast, when it came to taking pictures, participants using the mouse performed better with the discrete interface than participants using the continuous interface. It was inferred that this was because the command to hover could be issued with a single input in the former (but not the latter) case. Overall, participants using the game controller performed at least as well or better than participants using the mouse. This was the case whether participants rated themselves as video-game devotees or not. The game controller afforded both continuous control for continuous functions and discrete control for discrete functions.

Providing both camera views simultaneously compared with only one camera view at a time did not aid performance. If anything, performance was poorer when both views were displayed simultaneously. This may have been due to the reduced size of the sensor windows in the dual display compared with the single display.

Utilization and Dissemination of Findings:

The training protocols and performance measures developed for this research can be applied to develop simulation-based structured training for MAV operator training. Further work would be required to validate whether simulation training with these protocols transfers to live mission performance with actual MAVs. The successful use of flight simulators for initial and refresher pilot training for manned vehicles suggest the same strategy could be applied for unmanned vehicles. The training missions developed can also be used as research protocols to test the effects of variations in user interface design on operator performance and acceptance. SA Technologies adopted our simulation and mission protocols in order to investigate the effect of operator control unit screen size on operator performance.

The results of the interface manipulations investigated here suggest a simple heuristic for designing interface control methods. The control method should match the function of the command. A discrete command (like hover) is likely best implemented as a single discrete input. Inputs that control continuous movements through space, on the other hand, are likely best implemented as continuous inputs. Further research will be required to confirm if this rule of thumb holds up under a number of use cases.

TRAINING TO OPERATE A SIMULATED MICRO-UNMANNED AERIAL VEHICLE WITH CONTINUOUS OR DISCRETE MANUAL CONTROL

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TRAINING TO OPERATE A SIMULATED MICRO-UNMANNED AERIAL VEHICLE WITH CONTINUOUS OR DISCRETE MANUAL CONTROL

Introduction

The U.S. military is seeking the development of increasingly smaller and lighter unmanned aviation systems (UASs). The U.S. Defense Advanced Research Projects Agency (DARPA) began supporting the development of one-half-kg to eight-kg micro-aerial vehicles (MAVs) in 1997 and is currently supporting the development of 10-g nano-aerial vehicles (NAVs), according to Flight International (2005). The motivation for small UASs is to provide reconnaissance, surveillance, and target acquisition (RSTA) at the small unit level (e.g., platoons and squads). The small vehicle size is intended to permit transport by dismounted Soldiers and to allow maneuvering in tight spaces such as urban canyons. In addition, the low altitude flight envisioned for these systems could alleviate the need for air space coordination, allowing these small UASs to be launched at a moment's notice. Finally, the intention is that these vehicles be easy to operate, enabling rapid training and dispensing with the need for specialized, dedicated operators (Office of the Secretary of Defense, 2002).

The need to quickly and reliably train UAS operators requires that the human-system interface be intuitive and easy to master and that structured training be developed; however, developers of MAVs and NAVs are mainly concerned with vehicle technology. Attention to training requirements and human-system interaction issues are often neglected until late in the development stage. This can create problems such as the fielding of equipment without clear standards for training certification, and/or interface design features that are not well suited to the needs of the user.

The purpose of the present research was to establish how variation in operator interface design would impact performance during training to manually control a simulated MAV. The report also provides a review of some of the relevant issues involved in UAS operator training and performance.

Background

In manual control mode, a UAS operator can control maneuvers of the vehicle in near-real time (as opposed to way-point pre-programmed navigation, which is determined prior to launch); however, unmanned vehicle system design may constrain the operator's freedom to maneuver. Sometimes these constraints are imposed to lessen the training burden. For example, Honeywell's 2006 prototype MAV system limited the velocity of the MAV to six knots in manual mode, despite the capability of the system to fly at a speed of over 25 knots. This constraint was intended to prevent aerodynamic instabilities, which could occur if particular patterns of maneuver commands were issued when the MAV was traveling at faster speeds. By limiting velocity in manual mode, the need to train operators on the types of maneuvers they should not attempt at higher speeds was eliminated.

Discrete and Continuous Control Schemes

Even though system constraints can be beneficial at times, at other times these restrictions may not optimally support operator training and performance. One way in which UAV system design may potentially constrain users involves the chosen input method (discrete or continuous interfaces). For example, discrete input interfaces instruct the vehicle to make maneuvers with specific predetermined parameters and may simplify the task for the operator by limiting the possible inputs. In contrast, continuous input interfaces allow the user to make fine-grained adjustments along a continuum and to alter more than one parameter at a time, which may help operators navigate difficult terrain because they have more precise control of the vehicle. Figure 1 illustrates a discrete input control display (ICD). By selecting one of the arrows in the display scheme, the operator can instruct the vehicle to move up, down, laterally, rotate, or stop (hover), and these maneuvers are carried out at a predetermined speed. The vehicle keeps traveling in a certain direction until another command is entered. Selection of one input command cancels the previous command; thus commands can be given for only one degree of freedom of movement at a time (though inertia can result in maneuvers at oblique angles or at various speeds).

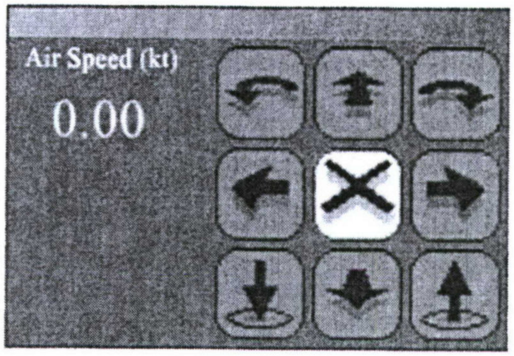

Figure 1. Illustration of a discrete input control display.

Figure 2 illustrates a more continuous input control scheme. Here, dragging one of the dots away from its initial "home" location causes the desired maneuver in that respective direction, with velocity increasing the further from home the dot is dragged (up to a maximum at the edges). The top arc acts like a steering wheel, controlling rotation. The side bar controls altitude (up-down), and the middle circle controls both forward-backward and lateral movement. A command to fly laterally and forward simultaneously can be given with one drag of the dot. In addition, in this continuous input scheme, issuing a command in one dimension does not cancel previously issued commands in the other dimensions. Thus, the operator has the ability to control maneuvers in multiple dimensions (multiple degrees of freedom) at one time.

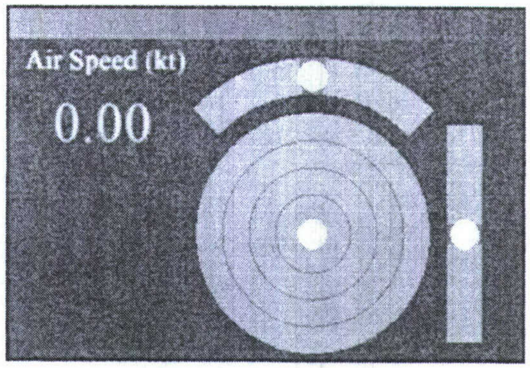

Figure 2. Illustration of a continuous input control display.

Existing operator interface designs for prototype and operational MAV systems have used either discrete or continuous control schemes, or some blending of the two; however, there has been little research on how these design decisions affect usability, mastery, or workload. Strommen (1993) found that young children playing a "capture the number" game captured more targets with a discrete control scheme than with a continuous control scheme if they were inexperienced with similar game environments; however, the control scheme failed to affect target capture in experienced players. It was suggested that discrete control may be especially helpful for novice users by reducing demands on working memory. Chen and Durfee (1993) found faster target acquisition times with discrete control than with continuous control when adults were tasked to manipulate a simulated robotic arm. The input methods were very different, however; discrete commands were given by voice (e.g., up, down, left, right), whereas continuous commands were given by the position of the shoulder. It is not clear whether discrete shoulder movements would have been superior to continuous shoulder movements.

Input Device Issues

The example of the robotic arm illustrates how the method of operator input (i.e., voice vs. shoulder position) could be a factor independent of or interactive with input scheme (i.e., discrete vs. continuous). Some methods of command input fit more naturally with discrete commands (e.g., voice), while others are more conducive to continuous control (e.g., a steering wheel). Wickens (1992) suggested that discrete voice commands are not well suited for conveying spatial and/or continuous input compared with discrete manual (hand-guided) input. Input devices for unmanned systems vary widely, including small computers using touch-based input (with a stylus), joysticks, wheels, natural language, and visual gestures (Chen, Haas, Pillalamarri, & Jacobson, 2006). In the present experiment, we compared the use of two different input devices. We chose one input device that seemed to naturally complement a discrete control scheme and one that seemed to naturally complement a continuous control scheme. For the former, we used a standard computer mouse. We chose the mouse as a surrogate for a touch-screen and stylus (a frequently used input method for MAVs). Both mouse and stylus use the point and click approach that directs the focus of attention away from the camera imagery view(s); however, with the mouse, inputs are more reliably registered. In our previous research with a touch screen and stylus, users became frustrated by touches that failed to register (Durlach, Neumann, & Bowens, 2006). We did not want input reliability to affect our measures in the current research, so we used a mouse instead. Previous research indicates little difference

in speed between a stylus and a mouse (Card, English & Burr, 1978; MacKenzie, Sellen & Buxton, 1991).

Half of the participants in the present investigation received training on simulated MAV control using the mouse. Of these, half entered inputs using the discrete input scheme illustrated in Figure 1, and the rest used the continuous input scheme illustrated in Figure 2. Thus, the effect of a strictly discrete input scheme vs. a more continuous input scheme could be assessed, holding input device constant.

While half of the participants used a mouse, the remainder of the participants received training on simulated MAV control using a dual-thumbstick game controller, as illustrated in Figure 3. Millions of people use this type of device to navigate through 3-D virtual environments while playing video games, and this is essentially what the operator of an unmanned system has to do. This type of game controller affords a more continuous form of input than either of the described point-and-click schemes. Each thumb stick can be used to control two dimensions of movement, and they can be operated in parallel. Not only can gradations in speed be controlled by how far the thumbstick is moved in any one direction, but also four dimensions of movement (up-down, forward-back, lateral movement left-right, and rotation) can be manipulated in parallel. For research participants equipped with the game controller, visual feedback on their thumb movements was supplied on the display. Half the participants equipped with the game controller had an interface display like the one shown in Figure 1. When the game controller was employed to maneuver the MAV, the arrows corresponding to the commanded maneuvers were illuminated. The rest of the participants equipped with the game controller had an interface display like the one shown in Figure 2. For these participants, when the game controller was employed to maneuver the MAV, the dots corresponding to the commanded maneuvers repositioned themselves to represent the current inputs.

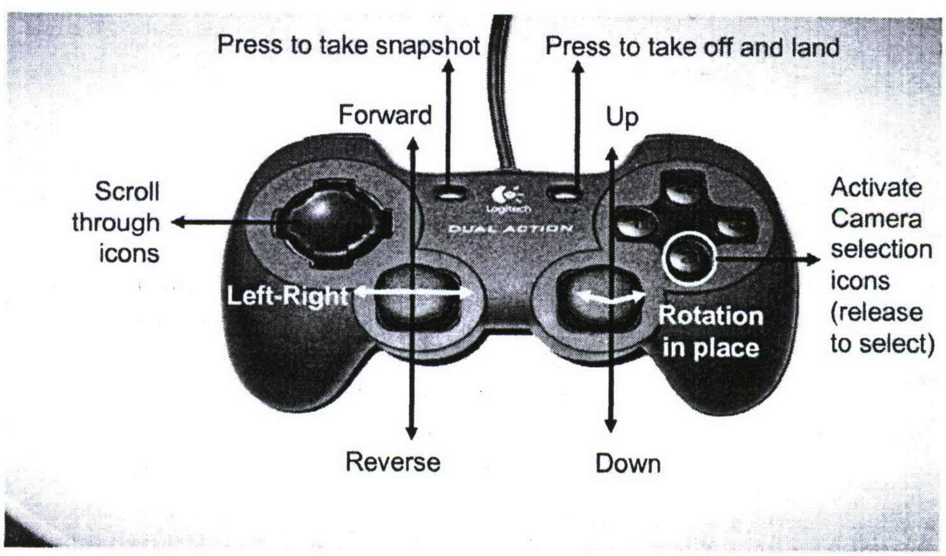

Figure 3. Illustration of the game controller with functions labeled. Left-right/lateral movements (left thumbstick) did not change vehicle heading.

In summary, there were four combinations of input device and display control scheme, which represented different degrees of continuity in the operator's ability to control the MAV. The combination of arrows and the mouse was the least continuous. The combination of dots and the mouse was somewhat more continuous, in that it allowed gradations in speed and simultaneous control of forward-backward and lateral movement. The combinations using the game controller were even more continuous because all inputs could be given in parallel. The only difference in these conditions was whether the graphical visual feedback provided speed information (dots) or not (arrows).

It could be argued that the more discrete the input scheme, the easier it should be to learn, because it involves managing fewer degrees of freedom at a time. On the other hand, more continuous methods provide more control. They could take longer to master, but could ultimately lead to more adept maneuvering. Learning to maneuver with the game controller may be particularly challenging for those unfamiliar with the device because they have to learn the mapping of thumb movements to MAV responses. Any attention toward their hands could detract from attention to the display (both sensor imagery and feedback scheme). The present research sought to examine these questions by comparing performance during training across the four conditions.

Sensor Imagery Issues

In order to employ an unmanned system for RSTA, the operator needs to interpret the sensory imagery returned from the vehicle sensors. Interpretation of sensor imagery is important for navigation, obstacle avoidance, and target detection. Electro-optical or infrared cameras providing streaming video are the most frequently employed sensors on MAVs; however, these sensors provide an impoverished view of the environment due to limited resolution, limited field of view, and vehicle vibration. When navigating oneself through space, there is a close coupling of visual and kinesthetic perception with action and continuous feedback between them. When navigating an unmanned system through space, perception and action are less tightly coupled, and this may interfere with judgment of scale, depth, and velocity (Chen, Haas, Pillalamarri, & Jacobson, 2006; Peruch & Mestre, 1999; Woods, Tittle, Feil, & Roesler 2004).

Different MAVs vary in whether their cameras are fixed, gimbaled, or have zoom capabilities, but they all tend to carry two cameras. One camera faces forward and the other downward. Another common aspect is that they display only one camera view to the operator at a time due to bandwidth limitations. Because of this, operators need methods to switch between camera views and to cognitively integrate past and current views (Goodrich & Olsen, 2003). Based on our past research (Durlach, Neumann, & Bowens, 2006), we hypothesized that display of both camera views simultaneously might facilitate MAV maneuver and situation awareness by essentially widening the field of view and allowing easier viewpoint switching. On the other hand, simultaneous displays might cause the operator to divide their attention between the views, which in turn might cause them to miss important information (Durlach, 2004). In addition, because the simultaneous views took up the same screen area as the single view, each camera image was smaller than the single camera image, and this might have negative affects on piloting and/or target detection (e.g., Stelzer & Wickens, 2006; Wickens, 2005). As we were operating in

a simulation environment and were not limited by bandwidth considerations, we were able to test these possibilities. Appendix B illustrates the different camera configurations on the operator control unit.

In summary, for this experiment three aspects of the operator's control interface were manipulated in order to assess the impact on performance and workload during training. The three factors each had two levels and were crossed, resulting in eight between-group conditions (2 x 2 x 2). The factors were input control device (mouse vs. game controller), input control display/scheme (continuous vs. discrete), and number of sensor views available at a time (one camera view vs. two camera views).

Description of the Simulated MAV

The simulated MAV was based loosely on Honeywell's 2005 t-MAV prototype, as illustrated in Figure 4 (Kennedy, Williams, Robertson, Pettitt, & Swiecicki, 2006), with vertical lift and land as well as hover capabilities. It had two fixed cameras facing forward and downward, which could send streaming video to the operator via the display on the OCU. Similar to the actual prototype, the airspeed of the simulated MAV was limited to six knots.

As no standard simulation training conditions, methods, or assessments existed for this prototype, we devised our own training methodology, which might be useful for adoption in the future. Trainees were first instructed on the MAV's capabilities and the basic functions of their designated OCU configuration. They were then given multiple practice exercises in which they had to complete a series of specific maneuvers within a set amount of time. They then had to complete two different maneuver-skill courses. Finally, if participants met certain criterion levels they went on to complete more demanding missions, during which their performance was measured to assess the impact of the OCU manipulations.

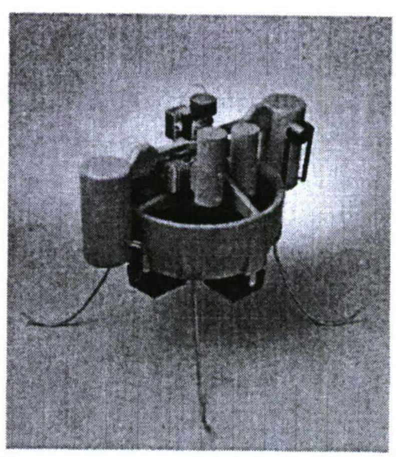

Figure 4. The 2005 t-MAV prototype by Honeywell.

Assessment of Individual Differences

We considered the possibility that trainees already familiar with game controllers might have a distinct advantage over participants not already familiar with them. We, therefore, asked participants about their video-game experience. This allowed us to take gaming experience into account when analyzing the results. We also assessed spatial ability. There is evidence that spatial ability, as assessed by psychometric tests, has moderate predictive validity for spatial knowledge acquisition in virtual environments (Waller, Knapp & Hunt, 2001), and all the performance missions involved some degree of navigation. In addition, the impact of number of camera views might depend on how well participants were able to mentally integrate the forward and downward views to form a cognitive representation of space. Based on arguments for multiple types of spatial intelligence (Gardner, 1999; Stumpf & Eliot, 1999; Thurstone, 1938), we gave four different tests intended to measure different aspects of spatial ability.

We did not initially attempt to equate gender across conditions; however, we realized there was a strong relationship between video game experience and gender among our sample when we analyzed a partial data set (28 participants) for a conference presentation (Neumann & Durlach, 2006). We found that the males reported higher levels of video game experience than females in our sample. Thereafter, we subsequently assigned trainees to conditions in order to ensure that an equal number of males and females contributed to each of the main effects. In this way, gender served as a rough proxy for equating video game experience across cells.

Method

Participants

Thirty-six male and 36 female participants from the University of Central Florida area completed the experiment in exchange for $20 or course credit. Three other people did not meet initial training criteria and were excused from the experiment. All participants were at least 18 years old and had normal color vision. The median age was 19 years. Each participant completed an informed consent form that explained the scope of the research prior to any testing.

Apparatus

The participant interacted with two lap-top computers. One of these displayed the OCU and controlled the simulation software. The other presented the NASA-TLX workload survey (Hart & Staveland, 1988). The participants interacted with these computers while seated at a desk. Another computer (desktop) ran OneSAF Testbed (OTB version 2.5), which allowed the injection of targets into the terrain database. The terrain database was modeled after an Army urban training site at Fort Polk, Louisiana.

The Simulated MAV

The characteristics of the simulated MAV were loosely based on the t-MAV developed under the Defense Analysis Research Project Agency's MAV Advanced Technology Demonstration. The MAV was a ducted-fan vertical lift vehicle which could hover, rotate in place, and travel at an airspeed of up to 6 knots under manual control. Based on available information about the t-MAV we developed a simple flight model, which caused the vehicle to tilt forward one degree for every knot of forward speed and which gave it some inertial properties (e.g., when in forward movement, it took time to actually stop and assume a hover after the hover command was issued). The simulated MAV was equipped with two fixed cameras, one facing forward, and one facing downward. The tilt produced by forward movement of the MAV also tilted camera angles (e.g. while moving forward, the downward camera pointed somewhat behind the vehicle).

Input Devices

Two input devices were used to operate the MAV. One was a standard 2-button/1-wheel Dell optical mouse with a USB connector, placed on a mouse pad, and the other was a Logitech dual-thumbstick game controller, also with a USB connector (see Figure 3). The devices enabled the same functions, only in different ways. Mouse clicks on OCU display activated those controls, whereas selection of the same function using the game controller activated the controls and produced the same visual feedback as if the mouse had been used.

Operator Control Unit

The OCU could be presented in one of four configurations (See Appendix B), created by crossing two two-level factors: camera views and input control scheme characteristics. The first factor was number of camera views displayed at a time; this could be one or two camera views. When there was only one overlapping camera view, participants could switch between the forward and downward camera views by using controls displayed on the OCU tool bar (mouse condition) or buttons on the game controller. Operators could take still photos of images in the active view by using controls similar to the camera switching controls. When there were two adjacent camera views, the active camera view had a blue border at the top of the view frame and a target indicator in the center of the image; the inactive camera view had a grey border at the top of the view frame. Operators could take still photographs of images in the active camera window and could choose which window was active using controls displayed on the OCU toolbar (mouse) or buttons on the game controller. All participants received auditory feedback when they took a snapshot (sound of a traditional camera shutter).

The second factor manipulated was the ICD. It could appear in one of two versions, which will be referred to as continuous or discrete. In the mouse conditions, participants clicked on the ICD to control the movement of the MAV. In the continuous case, the mouse was used to drag the dots to produce changes in rotation (upper arc), altitude (bar), or forward/backward and lateral (circle) movement. The further away a dot was dragged from the center of the circle,

the faster the MAV would travel (up to a maximum of 6 knots at the edges). Dots could be left in position to maintain speed and heading while the mouse was used for other functions (e.g., taking a snap shot or manipulating one of the other dots).

In the discrete case, the mouse was used to click on one of the directional arrows or a tool bar icon. Upon a click, the icon or arrow was highlighted to indicate it was selected. Selecting one of the arrows activated movement in the selected direction and cancelled any ongoing movement in another direction (with some inertia, so that the change was graded). After selection, movement in the chosen direction increased to 6 knots and then stayed at that speed until another maneuver icon was selected. Clicking on the "X" would cause all movement to slow until the MAV came to a stable hover.

In the game controller conditions, the ICD provided the same visual feedback (dots moved, or arrows and icons illuminated). The number of camera views and ICD were crossed to produce the four different OCU display configurations. These in turn were crossed with command input device to create eight conditions in total.

Besides these aspects, all OCU configurations displayed information to assist mission execution. An altimeter was displayed to the left of the sensor imagery (or camera view). Airspeed was displayed in the ICD. A satellite/map view of the terrain was presented to the right of the sensor imagery (the situational awareness view). During the experiment, the map scale and center were fixed. The current position of the MAV was always displayed on this map.

Timing of each exercise was initiated by the operator. When the operator activated the take-off icon and the MAV started to ascend, the timer was triggered. Timing ended when the MAV was grounded. Mission duration was displayed in the upper right corner of the OCU display. Each exercise or mission commenced with a launch from a predetermined spot and ended with a landing at a point designated in the instructions. Upon launch, the MAV rose to an altitude of 60 feet above ground and maneuver commands issued during this rise had no effects. When the MAV reached take-off altitude, a red stop sign icon on the menu bar illuminated. At this point, maneuver commands could be given.

Procedure

Each participant completed two sessions on separate days. In session 1, which lasted about an hour, participants completed a demographics questionnaire (see Appendix D) and four tests of spatial ability. The demographic survey contained questions on each user's computer usage and video game playing habits, as well as demographic data like gender, age, and education. The spatial ability tests included the Hidden Figures and Hidden Patterns Tests (ETS, 1976), and the Cube Comparison Test (ETS, 1976), as well as a spatial orientation test developed after Gugerty, Brooks, and Treadway (2005). The Hidden Figures and Hidden Patterns Tests from Educational Testing Services (ETS) measure flexibility of closure, also known as field independence. This involves picking out specific patterns or shapes embedded within distracting information. The Cube Comparison Test from ETS examines the ability to rotate images mentally in 3-D. The spatial orientation test measures the ability to judge the cardinal direction from a building to a target from different viewing directions.

MAV operator training took place during session 2, which lasted two to three hours. For this session, participants were semi-randomly assigned to one of eight conditions determined by a 2 x 2 x 2 between-groups design, where the three factors were input device (mouse or game controller), ICD (continuous or discrete), and number of camera views (one or two). The number of males and females in each condition is shown in Table 1.

Table 1
Gender Distribution among Conditions

Condition			Males	Females
Device	**Camera Views**	**Display**		
Mouse	1	Continuous	4	5
Mouse	1	Discrete	4	5
Mouse	2	Continuous	4	5
Mouse	2	Discrete	5	4
Game Controller	1	Continuous	4	5
Game Controller	1	Discrete	6	3
Game Controller	2	Continuous	4	5
Game Controller	2	Discrete	5	4

Each operator completed the training equipped with a printed manual (see Appendix C) and facilitated by the experimenter (the second author). Trainees were first instructed on the MAV's capabilities and the basic functions of their designated OCU configuration. The experimenter then administered and graded a short written test designed to assess the operator's knowledge of all the commands and interface components required for the research (see Appendix E). Any errors were re-trained. Participants were then given seven exercises in which they had to complete a series of specific maneuvers within a set amount of time. For the first three exercises, participants read a list of maneuvers to complete. For the fourth and fifth exercises, participants followed a series of verbal commands read aloud by the experimenter. As an example, Table 2 gives the instructions participants read for Practice Exercise 2. See Appendix C for complete participant training manual.

Table 2
Instructions for Practice Exercise 2

Practice Exercise 2:
1) Press OK to start the simulation and timer. 2) Execute the **Take-off** command. 3) At or before the completion of take-off, activate the view window for Camera 1 (forward view). 4) Take a snapshot with camera 1. 5) Activate the view window for camera 2 (down view). 6) Take snapshot with camera 2. 7) Execute the **Land** command. 8) This must be completed in <u>40 seconds</u> (:40) or less.

While the first five exercises involved simple maneuvers, the final two practice exercises involved negotiating timed courses. Before executing each exercise, the participant was allowed

to observe the MAV flying the course in automated mode. The "racetrack" course required operators to pilot the MAV for one lap around an oval-shaped course running through a village and then land on top of a marked rooftop. Red poles along the roadway marked the appropriate course. Participants were instructed to leave the red poles on their right and to complete the exercise without collisions. The "slalom" mission required operators to fly a slalom course marked out by six red and green poles. Participants were instructed to leave the red poles on their right and the green poles on their left. After weaving around the poles, participants had to turn 180 degrees and fly the same path back to the launch point. For both courses, the ideal path was displayed on the situation awareness map, and participants were able to observe at all times where the MAV was relative to the path drawn on the map. If the MAV collided with an obstacle (e.g., tree or building), the experimenter stopped the trial and had the participant start the exercise again from the beginning. Collisions with obstacles halted movement in the direction the MAV was traveling at the time of the collision and were visibly obvious. Collisions were also recorded automatically in log files.

Each participant was allowed up to five attempts to successfully complete each of the seven practice exercises. Participants who could not finish an exercise within five attempts were dismissed from the experiment.

After finishing the practice exercises, participants began a series of six missions, during which the main performance data were collected. Participants were told to complete each mission as quickly as possible but to avoid collisions. There were no performance criteria given to participants, no waypoints were visible on the situation awareness map, and missions continued to completion whether there were collisions or not. In order to continue after a collision, participants could back away from the obstacle and then resume movement around it. Table 3 provides a summary of these missions. The NASA TLX workload questionnaire was completed by participants at the end of each mission.

Table 3
Outline of missions. Number of Collisions Occurring and Self-rated Workload were Recorded

Mission Number	Name and other Measures	Description	Mean Workload
1	**Racetrack** Time	Maneuver an oval route with the aid of red poles placed to guide the path; land on a rooftop.	34.4
2	**Church** Time, Targets located	Free flight to a church (identified by a steeple); inspect all sides and determine number of friendly and enemy inside.	42.2
3	**Slalom** Time	Maneuver a slalom route with the aid of red and green poles (leave red on right and green on left); return to launch point.	38.7
4	**Reconnaissance** Number of targets photographed and recalled	Free flight to detect and photograph targets (Soldiers and vehicles). Pilot recalled to launch point after 7 minutes.	49.8
5	**Racetrack** Time	Same as Mission 1	31.4
6	**Slalom** Time	Same as Mission 3	33.1

During Mission 1, participants flew the racetrack course that had been part of the practice exercises; however, this time, the ideal path to follow was not displayed on the situation awareness map.

The next mission was the first of two tactical missions and involved flying to a designated building (a church) and identifying the occupants, as seen through the windows. Participants were briefed on their mission and shown pictures of friendly and enemy Soldiers. They were instructed to observe the church from several vantage points at close range to determine how many friendly and enemy Soldiers were inside.

During Mission 3, the participants flew the slalom course again; however, this time, the ideal path to follow was not displayed on the situation awareness map.

The next mission was a reconnaissance sortie. Twelve targets (eight vehicles and four dismounted infantry) were imported into the database. Operators received a mission briefing illustrating the potential targets. They were instructed to fly to the village and photograph as many of the targets as they could find (there were no distracters). Each target was to be photographed with both the forward and downward camera. Participants were not told how many targets there were or how much time they had to complete the mission. After seven minutes from launch, operators were instructed to return to the launch point immediately. After landing, they were given a debriefing during which each operator was asked to recall the type and location of entities observed during the flight. Participants indicated the targets they could recall by marking them directly on a scale map of the terrain. This post-test was later graded by the experimenter who used a transparent overlay to determine correctly marked entity locations. Scores were determined as follows: correctly identified targets located within .625" of the actual location of the entity (inside a 1.25" diameter circle traced on the overlay) received 2 points. Entities marked within 1" of the actual location (within a 2" diameter circle) received 1 point. Correctly labeling an entity's orientation also earned a point. Orientation for vehicles was always North.

Participants were subsequently instructed to repeat the racetrack mission and then the slalom mission (Missions 5 and 6). They then completed a usability survey which contained 31 items formatted using a 10-point scale with 1 indicating the most favorable response, and 10 the least favorable response (see Appendix F).

Measures and Analysis

Multiple measures of performance were collected for each mission, with some variation depending on mission. These included time-to-complete, number of collisions, number of targets observed, and/or photographed (church and reconnaissance missions), and self-rated workload. Before performing any formal analysis, data were screened for outliers and missing cells. Outliers were treated uniformly. After verifying the data were correctly entered, each outlier score was transformed to one measurement unit outside of the most extreme score that fell within +/- 2 SD of the mean (Tabachnick & Fidell, 1996). There were two instances of missing data: one male and one female participant incorrectly completed a single spatial test. These data were replaced by using the mean test score for their gender.

The correlations among the standardized scores on the spatial tests are given in Table 4. It can be seen in the table that there were moderate significant correlations among the different tests. Examination of first-order partial correlations indicated that none of the test scores acted as antecedents or interveners in the relation among any of the other two. This suggests that the tests measured related but distinct abilities. To control for individual differences when assessing the effects of the independent variables, the standardized spatial test scores were summed to create a single covariate for analysis of covariance (ANACOVA). The predictive relation between individual spatial test scores and specific measures of performance was further examined if the composite spatial score covaried with the dependent measure.

Table 4
Correlations among the Spatial AbilityTests

	Cube Comparison	Hidden Figures	Hidden Patterns	Spatial Orientation
Cube Comparison	-----	.39 *	.37 *	.27 *
Hidden Figures	-----		.42 *	.15
Hidden Patterns	-----	-----	-----	.27 *
Spatial Orientation	-----	-----	-----	-----

* $p < .05$

Responses to the three questions on the demographic survey relating to video-game experience (VGE) were highly correlated and combined into a single composite measure. This measure was correlated significantly with gender (Spearman $r = .75$), with higher video-game experience associated with males. The composite spatial scores were also correlated with gender (Spearman $r = .24$), with higher scores more likely to be from males. Spatial and VGE scores failed to be significantly correlated (Spearman $r = .15$). The eight conditions formed by the 2 x 2 x 2 design were checked for equivalence on VGE and spatial ability. No differences across conditions were detected.

The effects of the independent variables on the performance measures were assessed using ANACOVA, with the spatial ability and VGE scores as covariates. Exceptions were made for number of collisions and number of attempts (practice exercises). These count measures were highly positively skewed (i.e., mostly 0's for collisions, and mostly 1's for number of attempts). Consequently, nonparametric analysis was conducted for these two measures.

Effects reported as significant reached the conventional level of $p < .05$. If effects are not mentioned (e.g., higher order interactions), then $p > .05$. Effect sizes (d') for significant pair-wise comparisons are reported. This measure of effect size represents the difference between two means as a proportion of the pooled standard deviation.

Results

Practice Exercise Attempts

The practice exercises were intended to train operators to associate input controls with their corresponding functions and to navigate designated paths through the virtual environment. Table 5 shows the distribution of the number of attempts required for successful completion of each exercise. Both spatial ability and VGE were negatively correlated with number of attempts required. Higher spatial ability and greater VGE were associated with fewer required attempts. For the first five practice exercises, in which participants completed a series of directed maneuvers, the correlation between spatial ability and number of attempts was significant (Spearman $r = -.30$), whereas the correlation between VGE and number of attempts failed to reach significance (Spearman $r = -.14$). For the racetrack and slalom courses, in which participants piloted designated paths, both measures correlated significantly with number of attempts. For spatial ability Spearman $r = -. 27$ and for VGE Spearman $r = -.39$. The maximum number of attempts required to complete all 7 of the practice exercises by any single individual was 17. No significant effects of the independent variables on number of attempts were detected.

Table 5
Number of Participants Requiring 1 to 5 Attempts to Complete each Practice Exercise. For Exercises 1, 2, and 3Pparticipants Read a List of Maneuvers. For Exercises 4A and 4B participants Responded to a List of Maneuvers Said Out Loud by the Experimenter. The Final Two Practice Exercises Involved Negotiating Timed Courses (Racetrack and Slalom)

Attempts: Practice Exercise	Criterion Time (Minutes:Seconds)	1	2	3	4	5
1 (read)	0:30	72	0	0	0	0
2 (read)	0:40	72	0	0	0	0
3 (read)	1:35	41	24	6	0	1
4A (oral)	1:05	50	18	3	1	0
4B (oral)	1:25	49	17	5	0	1
Racetrack	3:50	47	13	7	3	2
Slalom	5:00	39	13	12	4	4

Racetrack Practice Criterion Time

Participants were required to navigate the racetrack course in 230s or less, without any collisions. They had the aid of an ideal path (waypoints) drawn on the situation awareness map. There failed to be any significant relation between the number of attempts required and the actual criterion times (Spearman $r = .11$). Neither were spatial ability nor VGE significant covariates of the criterion times. Criterion times, which are listed in Table 6, were significantly affected by interactions of input device and ICD, $F(1, 62) = 5.81$ and input device and number of camera views, $F(1, 62) = 8.69$; the three-way interaction failed to be significant ($F < 1$). As can be seen in the table, completion tended to be slower in the mouse conditions (mean 207.1 s) than the game controller conditions (mean 196.9 s); however, this was particularly the case when the mouse was combined with two simultaneous camera views (mean 211.2 s) or with the discrete

ICD (mean 212.6 s). Analysis of the mouse conditions indicated main effects of both ICD, $F(1, 30) = 7.74$, and number of camera views, $F(1, 30) = 4.28$. In contrast, analysis of the game controller conditions failed to suggest any significant effects of these variables.

Table 6
Mean Time in Seconds to Complete the Racetrack and Slalom Courses on the Attempt for which the Temporal Criterion (230 Seconds for Racetrack and 300 Seconds for Slalom) was Met.

Input Device	Camera Views	ICD	Racetrack Criterion Time Mean (s.e.)	Slalom Criterion Time Mean (s.e.)
Mouse	1	Discrete	209.4 (3.0)	258.9 (21.8)
Mouse	1	Continuous	196.7 (4.2)	230.7 (35.1)
Mouse	2	Discrete	215.8 (3.3)	243.9 (23.3)
Mouse	2	Continuous	206.5 (4.6)	234.7 (26.3)
Game-Controller	1	Discrete	196.8 (4.4)	225.6 (29.8)
Game-Controller	1	Continuous	201.8 (4.5)	226.1 (16.6)
Game-Controller	2	Discrete	191.2 (3.7)	215.8 (21.9)
Game-Controller	2	Continuous	197.6 (4.9)	227.3 (25.8)

Racetrack Missions

Figure 5 illustrates the mean time to complete the racetrack missions for the two times it was completed during the mission phase of the experiment (Missions 1 and 5). During the mission phase, there was no time criterion and the run went to completion whether there was a collision or not. No path was displayed on the situation awareness map. VGE and spatial ability failed to be significant covariates of mission time. It can be seen in the figure that mission time decreased from the first to the second repetition, $F(1, 62) = 15.90$, $d' = .43$. There was also an input device by ICD interaction, $F(1, 62) = 15.9$. In the discrete ICD conditions, participants using the mouse were significantly slower to complete the course than participants using the game controller. In the continuous ICD conditions, there failed to be any difference due to input device. According to post hoc tests (Tukey HSD), participants in the mouse-plus-discrete ICD were significantly slower than participants in any of the other conditions.

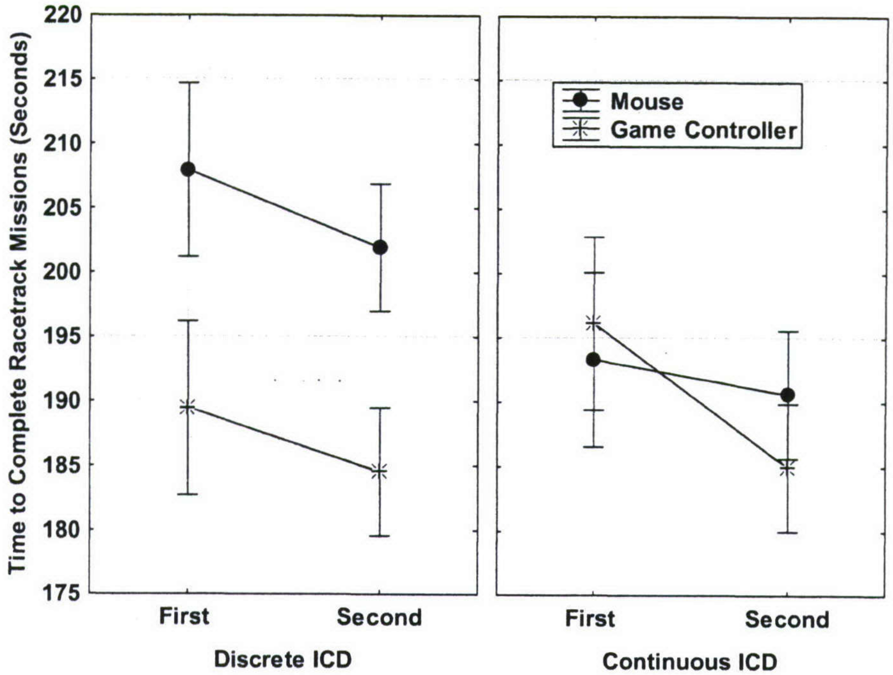

Figure 5. Mean seconds to complete the racetrack missions for its two repetitions (first and second). The left panel shows the results for the discrete ICD condition, and the right panel for the continuous ICD condition. Vertical bars show 95% confidence intervals.

Seven participants had at least one collision during the first repetition of the racetrack mission, and 11 had at least one collision during the second repetition. None of these were the same participants. Some participants expressed determination to better their completion time on the second repetition (even though they were not instructed to do so). Consequently, they may have taken more risk in flight than was prudent. There failed to be a systematic pattern between condition and collisions. Neither was there any significant relationship detected between collisions and spatial ability or VGE.

Mean subjective workload was 32.9 for the racetrack mission, averaged across conditions and repetition. There failed to be any detectable effect of condition or repetition; however, VGE was a significant covariate of workload scores, $F(1, 62) = 11.04$. Higher VGE was associated with lower workload scores.

Slalom Practice Criterion Time

Participants were required to navigate the slalom course in 300 seconds or less, without any collisions. They had the aid of an ideal path drawn on the situation awareness map. There failed to be any significant relation between the number of attempts required and the actual criterion times (Spearman $r = .16$). VGE was a significant covariate of completion time, $F(1, 62) = 5.02$, with higher VGE associated with lower times. As can be seen in Table 6, mean criterion times were higher for participants using the mouse (mean 241.7 s) than the game controller (mean 223.0 s); however there was an interaction of input device and ICD, which modulated this

difference, $F(1,62) = 4.8$. Analysis of the mouse conditions indicated a significant effect of ICD, $F(1, 30) = 4.309$, with those in the discrete condition performing more slowly. For the game-controller conditions, there failed to be an effect of ICD.

Slalom Missions

Figure 6 illustrates the mean time to complete the slalom missions for the two times it was completed during the mission phase of the experiment. During the mission phase, there was no time criterion, and the run went to completion whether there was a collision or not. No path was displayed on the situation awareness map. VGE and spatial ability failed to be significant covariates of mission time. It can be seen in the figure that mission time decreased from the first to the second repetition, $F(1, 62) = 44.31$. It can also be seen that participants using the mouse were slower to complete missions than participants using the game controller, $F(1, 62) = 12.55$. There was also an interaction of input device and repetition, $F(1, 62) = 4.36$. The differences due to input device were greater on the first than the second repetition. A post hoc test (Tukey HSD) indicated that within each input condition there were significant time decreases from repetition one to repetition two ($d' = 1.30$ and .45 for mouse and game controller conditions, respectively). Across conditions, input device had a significant effect during repetition one ($d' = .84$), but failed to do so during repetition two. The interaction of input device and ICD, which was found for the slalom practice, failed to be significant for the slalom missions.

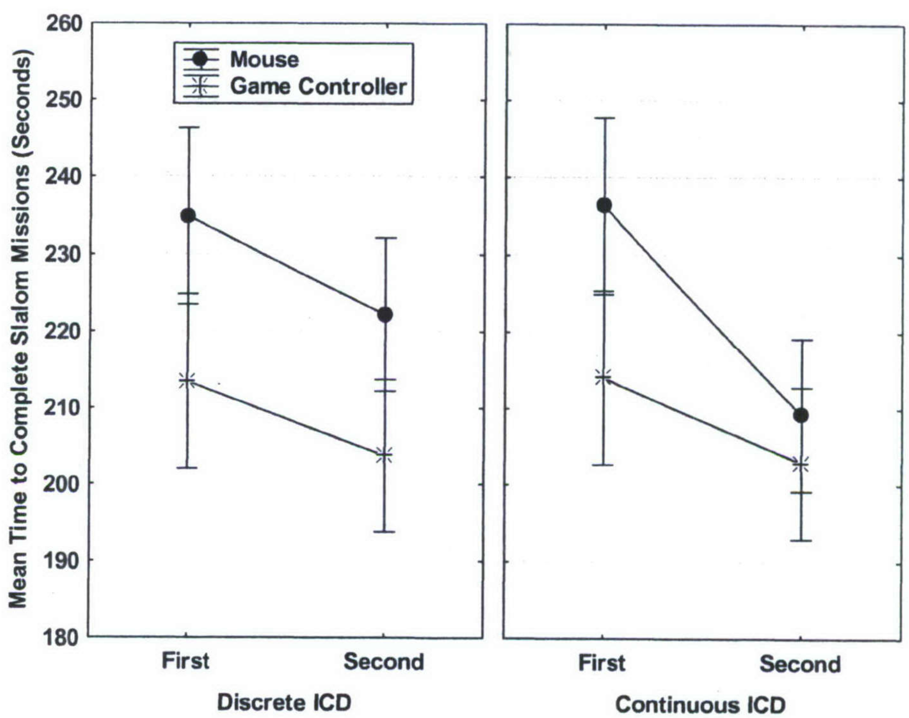

Figure 6. Mean seconds to complete the slalom missions for its two repetitions (first and second). The left panel shows the results for the discrete ICD condition, and the right panel for the continuous ICD condition. Vertical bars show 95% confidence intervals.

Sixteen participants had at least one collision during the first repetition of the slalom mission, and 16 had at least one during the second repetition. Of these, six had collisions during both. There failed to be a systematic pattern between condition and collisions. Neither was there any significant relationship detected between collisions and spatial ability or VGE.

VGE was a significant covariate of workload ratings for the slalom mission, $F(1, 62) = 5.40$, with higher VGE associated with lower workload ratings. Mean workload for the first and second slalom repetitions was 38.7 and 33.1, respectively. This decrease was significant, $F(1, 62) = 25.21$, $d' = .26$; but the effect of repetition interacted with both input device, $F(1, 62) = 4.70$, and ICD, $F(1, 62) = 9.90$. With respect to input device, a post hoc analysis indicated that the decrease was significant only in the mouse conditions (40.5 to 32.5, $d' = .38$). With respect to the ICD, a post hoc analysis indicated that the decrease was significant only in the continuous conditions (38.29 to 29.35, $d' = .45$).

Church Mission

This mission required participants to locate the church and inspect it from all sides to determine who was inside (two friendly and two enemy Soldiers). Only 48 of the 72 participants accurately reported this. Those who were inaccurate failed to inspect the church from all sides, and consequently had much shorter times to complete the mission. Because of this, only data from the 48 accurate participants were analyzed. The number of accurate participants in each of the eight conditions ranged between three and nine, and was not systematically related to condition.

VGE was a significant covariate of time to complete the church mission, $F(1, 38) = 8.30$, with greater VGE associated with shorter times. Figure 7 illustrates the effect of input device and number of camera views on time to complete the church mission. Participants completed the mission faster with the game controller (N = 27) than the mouse (N = 21), $F(1, 38) = 12.90$, $d' = .97$. They also completed the mission faster with only one, as compared with two camera views (N= 24 for each condition), $F(1, 38) = 7.17$, $d' = .64$.

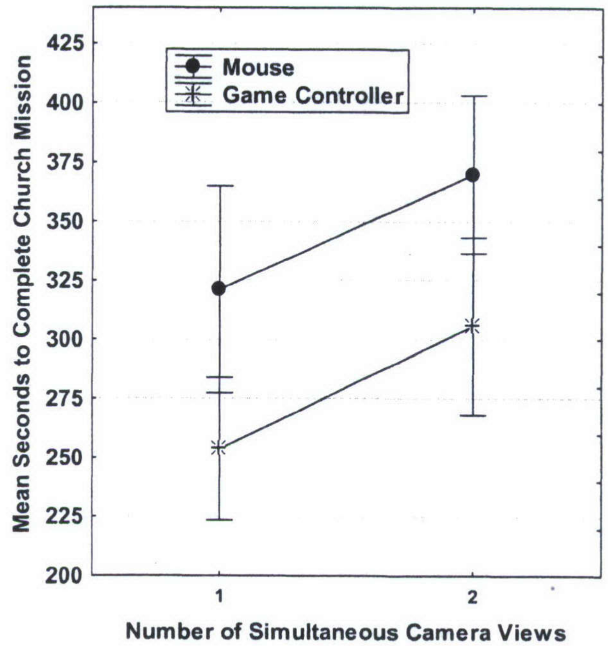

Figure 7. Mean seconds to complete the church mission, according to the input device and the number of simultaneous camera views. Vertical bars show 95% confidence intervals.

Only eight of the 27 participants using the game controller collided with an obstacle during the church mission, whereas 13 of the 21 participants using the mouse did so. This difference was significant according to a two-tailed Fisher exact test. The other independent variables failed to affect collisions. VGE correlated significantly with number of collisions (Spearman $r = -.36$).

VGE was a significant covariate of workload ratings, $F(1, 38) = 6.67$, with higher VGE associated with lower workload scores. Participants rated workload higher if using the mouse (mean 44.6) than if using the game controller (mean 32.5), $F(1,38) = 5.44$, $d' = .32$.

Reconnaissance Mission

For number of targets photographed, a full point was awarded for each target photographed with both the forward and downward cameras, and ½ point for each target photographed with only one of the cameras (no extra points were awarded for additional photos of a target once one forward and one downward picture were taken). Therefore, the maximum possible score was twelve. Both VGE and spatial ability were significant covariates of number of targets photographed. For VGE, $F(1, 62) = 10.10$, and for spatial ability, $F(1,62) = 16.26$.

Figure 8 shows the mean number of targets photographed, according to input device and ICD. Participants using the game controller photographed significantly more targets than those using the mouse, $F(1, 62) = 28.44$, $d' = .95$. There was also an interaction of input device and ICD, $F(1, 62) = 5.23$. The combination of the mouse and the continuous ICD yielded the lowest

mean number of photographs, and according to a Tukey HSD test, this condition differed significantly from both game controller conditions, and marginally significantly (adjusted $p <$ .06) from the mouse and discrete ICD condition. For this latter comparison, $d' = .74$.

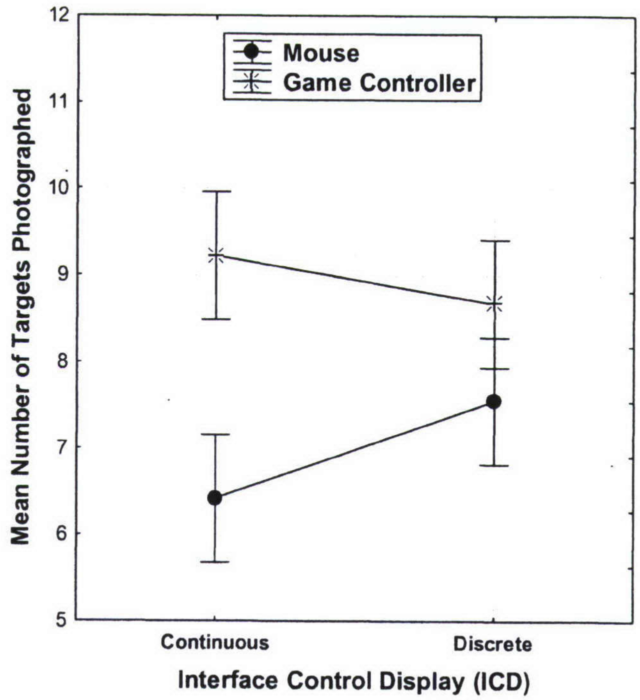

Figure 8. Mean number of targets photographed during the reconnaissance mission, according to input device and ICD. Vertical bars show 95% confidence intervals.

Subsequent to landing, each participant was asked to recall the type and location of entities observed during the flight by marking target locations on a scale map of the terrain. In order to receive one point, the target type had to be correctly indicated and fall within a 2" diameter circle around the actual target location. Correct identifications within a 1.25" diameter circle received two points. Correctly labeling an entity's orientation earned an additional point (all targets were oriented north). Thus, the maximum possible score on this measure was 36 (three points per target). The mean target recall score was 12.7 (standard deviation = 5.4). None of the independent variables had a significant effect on recall scores; however, both VGE and spatial ability were significant covariates. For VGE, $F(1, 62) = 9.56$, and for spatial ability, $F(1, 62) = 4.59$.

Forty-six of the 72 participants committed at least one collision during the reconnaissance mission. Median number of collisions was 1.0. Whether a participant had a collision or not was unrelated to condition statistically; however, there was a significant relationship between spatial ability and number of collisions (Spearman r =-25). Higher spatial ability tended to be associated with fewer collisions.

VGE was a significant covariate of workload, $F(1, 62) = 7.0$, with higher VGE associated with lower rated workload. The independent variables failed to significantly affect workload during this mission.

Relation between Individual Spatial Ability Tests and the Dependent Variables

According to the analyses above, spatial ability correlated with number of attempts to complete the practice exercises, number of targets photographed and recalled, and number of collisions in the reconnaissance mission. Although not the main purpose of this experiment, we evaluated whether the individual spatial tests differed in their ability to predict variation in these dependent variables. For number of attempts to complete practice exercises and collisions, we examined Spearman correlations because the data did not conform to the assumptions required for parametric analysis. Table 7 shows the Spearman correlations between the individual spatial ability tests and these dependent variables. For the directed maneuver exercises (practice exercises 1–5), there were significant correlations between the Cube Comparison test and the Hidden Patterns test with number of attempts required. For the racetrack course, there were significant correlations between the Hidden Patterns test and the Hidden Figures test with number of attempts required. For the slalom course, there failed to be any significant correlations. For the reconnaissance mission, there was a significant correlation between collisions and the Hidden Patterns test.

Table 7
Spearman Correlations between Dependent Variables and the Individual Spatial Ability Tests

	Directed Maneuver Attempts	Racetrack Attempts	Slalom Attempts	Recon Mission Collisions
Cube Comparison	-.27*	-.14	.00	-.19
Hidden Figures	-.10	-.34*	-.07	-.14
Hidden Patterns	-.35*	-.27*	-.01	-.32*
Spatial Orientation	-.10	-.12	-.14	-.13

* $p < .05$

For the number of targets photographed during the reconnaissance mission, we conducted an ANACOVA with VGE and all four spatial tests as covariates, and the three manipulated factors (input device, ICD, and number of camera views). According to this analysis of the four spatial tests, only the Hidden Patterns test was a significant covariate, $F(1, 59) = 4.93$. An analogous ANACOVA for number of targets recalled (drawn on the map post-mission) indicated that none of the individual spatial tests were significant covariates.

In summary, the Hidden Patterns test had the most consistent ability to account for variation in these dependent variables. For two of the analyses, no individual tests correlated significantly with the dependent variable examined despite significant correlations between the composite spatial measure and the dependent variables.

Usability

Overall, usability was rated more favorably by participants who used the game controller than by participants who used the mouse, $F(1, 62) = 6.16$, $d' = .56$. Averaged over all the 31 questions, the mean usability score was 2.3 for the game controller condition and 2.8 for the mouse condition (with lower scores indicating more favorable ratings). The extent of the difference caused by input device depended on the individual questions. There was a question by input device interaction, $F(1, 1860) = 3.16$. The ratings from the game controller condition were significantly more favorable than from the mouse condition for nine questions. These included ratings of the system overall, system feedback, ease of controlling the MAV, and the ability to maintain awareness of mission objectives. The specific data associated with these questions are listed in Table 8.

Table 8
Mean Usability Questions for which Participants Using the Game Controller (GC) Gave Significantly More Favorable Ratings (Lower Scores) than Participants Using the Mouse, along with Corresponding Statistics

Usability Question	Mean Mouse	Mean GC	$F(1,62)$	d'
The system I worked with was 1 Easy---------------------------- Difficult 10	3.3	2.6	8.97	.69
When controlling the MAV in flight using the input device was 1 Easy---------------------------- Difficult 10	4.0	2.3	46.72	.78
When using the input device to enter flight commands to the MAV, maintaining awareness of individual mission objectives was 1 Easy---------------------------- Difficult 10	3.3	2.2	9.01	.69
When giving commands to move forward, back, left & right, the air vehicle reacted as I expected. 1 Always -------------------------- Never 10	3.6	2.4	12.01	.76
When giving commands to move up, down & rotate, the air vehicle reacted as I expected. 1 Always -------------------------- Never 10	3.6	2.5	6.74	.60
The system provided adequate feedback when I issued a command to the MAV. 1 Always -------------------------- Never 10	2.7	2.0	5.76	.54
The OCU interface keeps you informed about what it is happening. 1 Always -------------------------- Never 10	2.7	2.0	6.41	.57
Correcting your mistakes was 1 Easy---------------------------- Difficult 10	3.4	2.6	4.48	.49
Both experienced and inexperienced users' needs were taken into consideration. 1 Always -------------------------- Never 10	2.5	1.8	5.07	.53

There were only three questions (out of 31) for which the scores were reversed, and only for one of these was the difference significant. This question was "System speed was," with options 1 to 10 where 1 was "fast enough" and 10 was "too slow." Mean ratings for this question were 3.2 and 4.7 for the mouse and game controller conditions, respectively, $F(1, 62) = 6.04$, $d' = .56$. We had intended this question to be about the responsiveness of the OCU, but many participants asked if this was about the speed of the MAV. They were instructed to make their own interpretation. The results on this question, therefore, indicate that game controller users were more likely to think they could handle a faster vehicle or a more responsive OCU than the mouse users did.

With respect to VGE and spatial ability, there was a lack of parallelism across usability questions. In other words, these measures correlated with usability responses for some questions, but not others. The interactions between question and VGE, and question and spatial ability were significant, F's $(1, 1860) = 1.72$ and 1.97, respectively. Table 9 lists the five questions for which one or both of the measures correlated significantly, along with the Spearman correlations. Higher spatial ability was associated with less frustration and confusion, and greater confidence about flying a real vehicle. Higher VGE was associated with higher perceived ease of use and greater confidence about flying a real vehicle; but also with less satisfaction with status messages.

There was a significant positive association between average usability ratings and average workload ratings. Lower workload ratings were associated with more favorable usability ratings (Spearman $r = .50$).

Table 9
Usability Questions which Produced Ratings Significantly Correlated with VGE or Spatial Ability, Along with the Spearman Correlations

Usability Question	**VGE**	**Spatial Ability**
The system I worked with was 1 Easy-- Difficult 10	-.24*	-.22
I found this experience 1 Satisfying--- Frustrating 10	-.17	-.31*
Current status (such as Taking off, Landing, Grounded) messages were 1 Adequate-- Inadequate 10	.30*	-.01
When piloting the MAV in manual control, determining the current heading of the MAV from the 360-degree directional heading tape was 1 Clear -- Confusing 10	-.19	-.29*
After this training, I am ready use this system to fly a real air vehicle 1 Very confident -------------------------Not at all confident 10	-.39*	-.27*

** indicates significance at the .05 level. A negative correlation indicates that higher VGE or spatial ability corresponds to more favorable usability ratings.*

Discussion & Conclusions

MAVs and NAVs have limited battery and/or fuel capacity. Consequently, the ability of operators to complete missions as quickly as possible is an important skill. According to the present data, time to complete missions was affected by input device or an interaction of input device and ICD. In general, missions took longer to complete with the mouse, especially when the mouse was combined with the discrete ICD. Times for the mouse-plus-continuous ICD condition produced completion times similar to the game controller conditions in some cases (e.g., racetrack course), but similar to the mouse-plus-discrete ICD condition in other cases (e.g., church mission). The specific pattern may have depended on mission difficulty. When workload was rated relatively low (e.g., racetrack), presumably the mission was relatively easy; participants in the mouse-plus-continuous ICD condition were able to complete the mission as quickly as participants with the game controller. When workload was rated relatively high (e.g., church mission), presumably the mission was relatively challenging. Participants in the mouse-plus-continuous ICD were unable to complete the mission as quickly as participants with the game controller. Instead, their performance resembled that of the mouse-plus-discrete ICD group. Notably for the church mission, workload was rated significantly lower by participants using the game controller than by participants using the mouse. Also for the church mission, the number of collisions was significantly lower by participants using the game controller than by participants using the mouse.

The pattern suggests that missions were most efficiently conducted with the game controller, least efficiently conducted with the mouse-plus-discrete ICD, and that the mouse-plus-continuous ICD was intermediate to these. However, this generalization does not fit with the reconnaissance mission data. All participants were given the same amount of time to complete the reconnaissance mission and the key data were number of targets photographed. While more targets were photographed by game controller users than by mouse users, there was an interaction of input device and ICD such that mouse users with the discrete ICD managed to photograph more targets than mouse users with the continuous ICD. This poor performance with the mouse-plus-continuous ICD (relative to the mouse and discrete ICD) does not fit with the simple characterization given above, but might be understood with some reflection on the mission requirements. In order to photograph targets, participants had to line up the target indicator on the target by maneuvering the MAV (because the cameras were fixed). A common strategy was to bring the MAV to a hover with the target indicator near the target, and then to make fine-grained movements to get the indicator lined up on the target before taking the picture. With the game controller the MAV could be put into a hover simply by releasing the thumb switches. With the discrete ICD, the MAV could be put into a hover simply by clicking on the X. In contrast, with the continuous ICD, the command to hover was more demanding. All the dots had to be returned to their home base, so multiple actions may have been required to put the MAV into a hover. It is possible that extra actions required in the mouse-plus-continuous ICD condition account for the fewer photographs taken in this condition.

Consideration of the time data and the reconnaissance mission data together suggests a rather common sense rule of thumb for designing discrete vs. continuous interface control schemes. The control method should match the function of the command. A discrete command (like hover) is likely best implemented as a single discrete command. Inputs that control

continuous movements through space, on the other hand, are likely best implemented as continuous commands. A good method for making the MAV stop is not simply "undoing" what makes the MAV go, as illustrated in the mouse-plus-continuous ICD condition.

Besides the continuous control of maneuver that the game controller afforded, it may have provided operators with another advantage. Once the functions of the game controller buttons are learned, the user has little need to remove attention from the sensor imagery. In contrast, for a point and click method, such as a mouse or a touch-screen, the user has to divert attention from the sensor imagery to the ICD or other iconology every time a new instruction is issued. This is because users have to ensure they point to the right location for the intended command. Any input method which allows for focused visual attention on the sensor imagery, instead of one which requires frequent shifts of visual attention away from it, will likely produce superior performance. More focused attention on the sensor imagery may improve performance for several reasons. First, it may simply be more efficient. Less time is required because imagery interpretation and command execution can be performed in parallel. Second, it may be less cognitively taxing than having to repeatedly re-orient visual attention from one part of the display to another (Rubinstein, Meyer, & Evans, 2001; Wickens & Liu, 1988). Third, it may lessen opportunities for change blindness, i.e., the tendency to miss imagery changes occurring while attention is diverted to other aspects of the OCU (Durlach, 2004; Durlach and Meliza, 2004). Fourth, it may facilitate the operator's processing of and learning about features in the environment in support of navigation and collision avoidance, such as the spatial relationships among landmarks.

The manipulation of one vs. two camera views did not have the expected impact on performance. Our original hypothesis was that two views might improve performance by allowing better spatial awareness and eliminating the task of view switching. Contrary to these expectations, when there was a significant effect of camera views, performance was impaired in the two-view condition (e.g., church mission time). This might have occurred because the simultaneous views took up the same screen area as the single view. Consequently, each image was smaller, and this might have had negative effects on piloting and/or target detection (e.g., Stelzer & Wickens, 2005; Wickens, 2005). The church mission may have been particularly sensitive to these effects because it required careful maneuvering around the church as well as target identification (friend or foe).

VGE and spatial ability were measured in order to control for participant differences in these variables and therefore more clearly reveal the effects of the independent variables. Nevertheless, the relation among VGE, spatial ability, and the performance measures are of some interest in their own right. Higher VGE was associated with faster mission completion, fewer collisions, more photographs taken, more targets recalled and lower workload scores. This is hardly surprising because, essentially, the MAV simulation is a video game. It has been suggested that VGE may result in changes in visual attention (Green & Bavelier, 2003). Such changes might account for the association between VGE and better performance. On the other hand, such effects have not been easily replicated (Castel, Pratt, & Drummand, 2005; Durlach, Kring, & Bowens, in press). It may be that higher VGE is simply associated with greater acceptance of and comfort in simulation environments. Higher VGE was associated with better performance regardless of input device. Thus, it was not merely due to greater familiarity with

the game controller device, but rather to some general effect on operating in a simulation context. It is unknown whether this effect will generalize to operation of a real (as opposed to simulated) MAV system.

Higher spatial ability was associated with the need for fewer attempts to complete the practice exercises. Spatial ability also accounted for some of the variation in performance on the reconnaissance mission. For the reconnaissance mission, higher spatial ability was associated with fewer collisions, more targets photographed, and more targets recalled. The reconnaissance mission was rated the most demanding, in terms of workload; so, it may be that the other missions failed to reveal an impact of spatial ability because they were not challenging enough. In terms of usability ratings, higher spatial ability was associated with less frustration and confusion, and greater confidence about flying a real vehicle. With respect to the four spatial ability tests used, the hidden patterns test appeared to be most predictive; however, there were instances where the composite spatial ability score significantly correlated with performance, but each individual test failed to do so.

Besides evaluating the impact of input device, ICD, and number of camera views, one of the purposes of this research was to design simulated missions that could be used for operator training and to suggest measures which could be used to track the course of operator mastery. Our intention was to train all the elements of control that an operator might need in manual mode. In order to do this, we devised what we considered to be increasingly difficult exercises and missions. We included repetitions of the racetrack and slalom courses in order to provide evidence of improvement. From the present data it is not really possible to describe the source of the improvement observed, however. It may have been due to mastery of flight controls and improved understanding of the simulated MAV's flight dynamics. It also may have been due to greater familiarity with the simulated environment. Because all the exercises were conducted in the same environment, participants had the opportunity to learn the location of obstacles (e.g., trees), the layout of the town, and useful landmarks to guide their flight. It is not clear to what extent learning about the spatial layout of the environment accounted for improved mission performance. To separate the effects of learning actual flight control from learning about environmental cues, performance must be tested in a novel environment.

The participants in this experiment had, on average, two hours of training, so it is possible that performance could have improved even more. The fact that some participants had collisions during the last mission attests to this. It is possible that a greater amount of training could alter some of the effects observed in the experiment. For example, with more experience operators might actually benefit from simultaneous camera views. Multiple views might also have proved advantageous had we tested in a novel environment. These possibilities can only be addressed with additional research.

While two hours of manual mode training does not seem like a lot, it may not be very far out of line with what operators will actually receive. Manual mode training is just one of the many elements of MAV employment that requires training (Durlach, 2007). For example, operators must be trained on vehicle assembly, maintenance, power, communications, terrain and weather effects, waypoint navigation, mission planning, and tactics. With limited time available for training, it is important that training be designed to be as efficient and effective and that the

OCU be designed to provide the affordances that will best support the operator's tasks. The present results suggest a fairly common sense heuristic: continuous control for continuous functions and discrete control for discrete functions.

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Appendix A

Acronyms

ANACOVA	Analysis of Covariance
ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
DARPA	Defense Advanced Research Projects Agency
ETS	Educational Testing Service
ICD	Input Control Display
MAV	Micro-Aerial Vehicle
NAV	Nano-Aerial Vehicle
OCU	Operator Control Unit
RSTA	Reconnaissance, Surveillance, and Target Acquisition
UAS	Unmanned Aviation Systems
VGE	Video Game Experience

Appendix B

Illustrations of Operator Control Unit Display Configurations

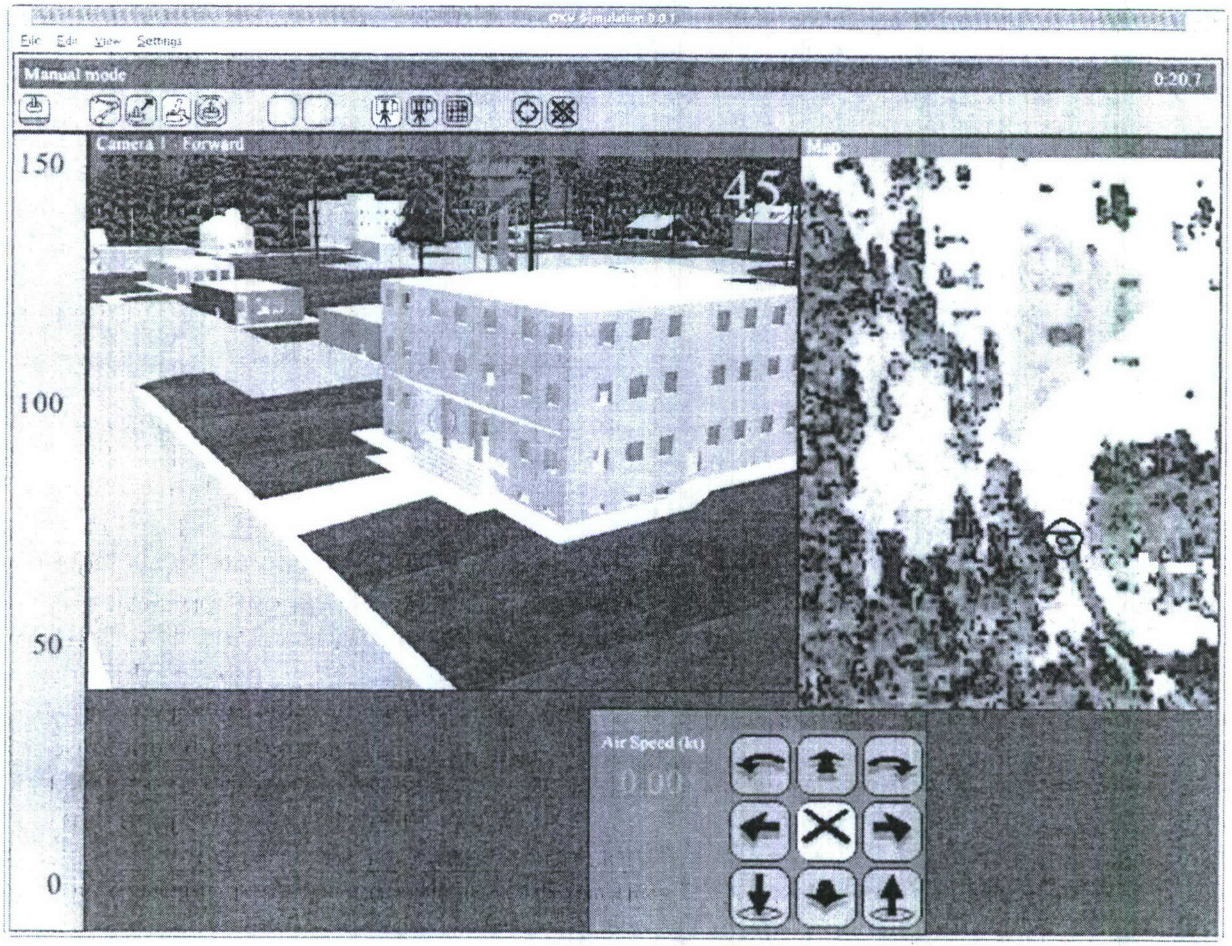


Figure B-1. OCU, single view camera layout with discrete input control.

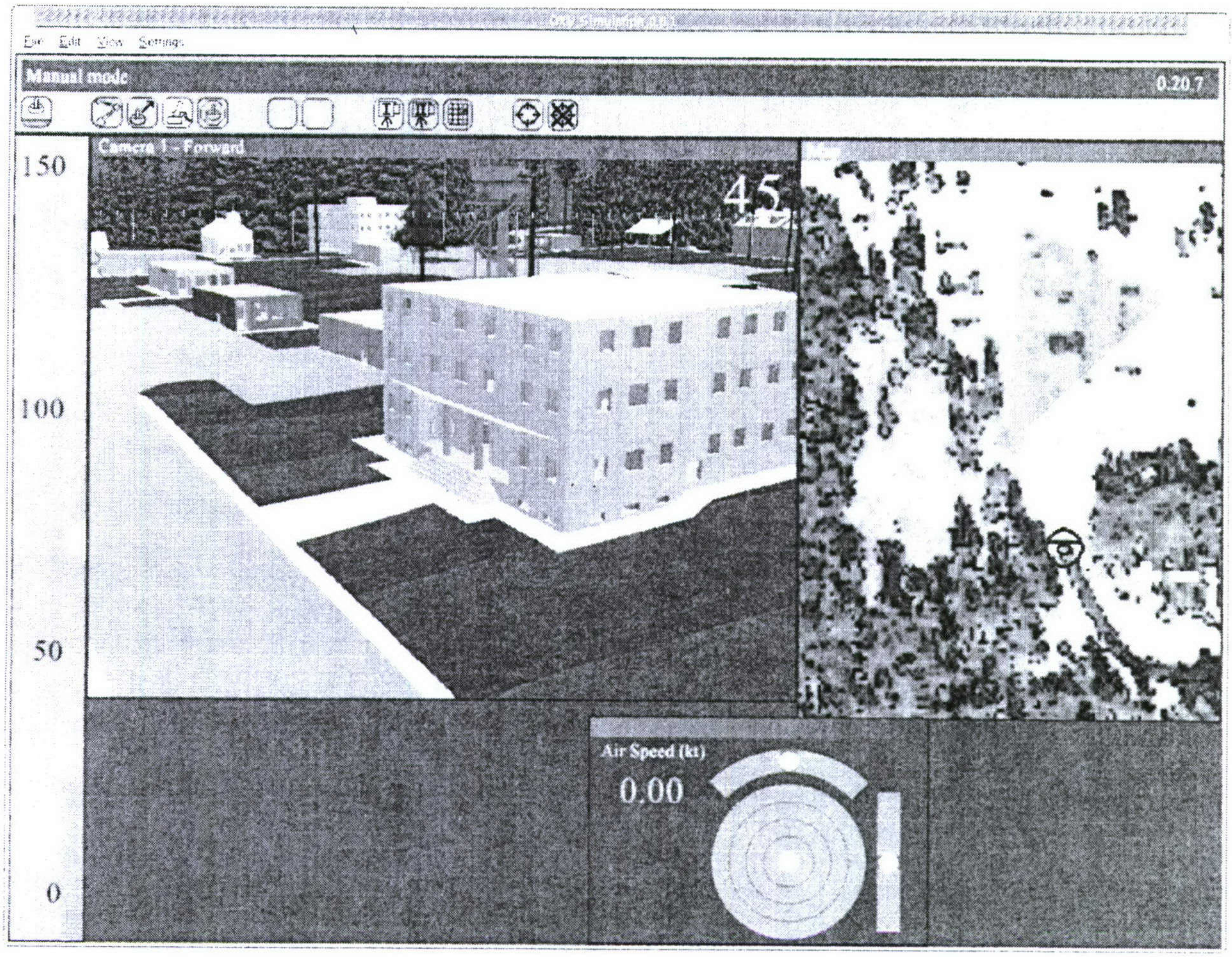


Figure B-2. OCU, single view camera layout with continuous input control.

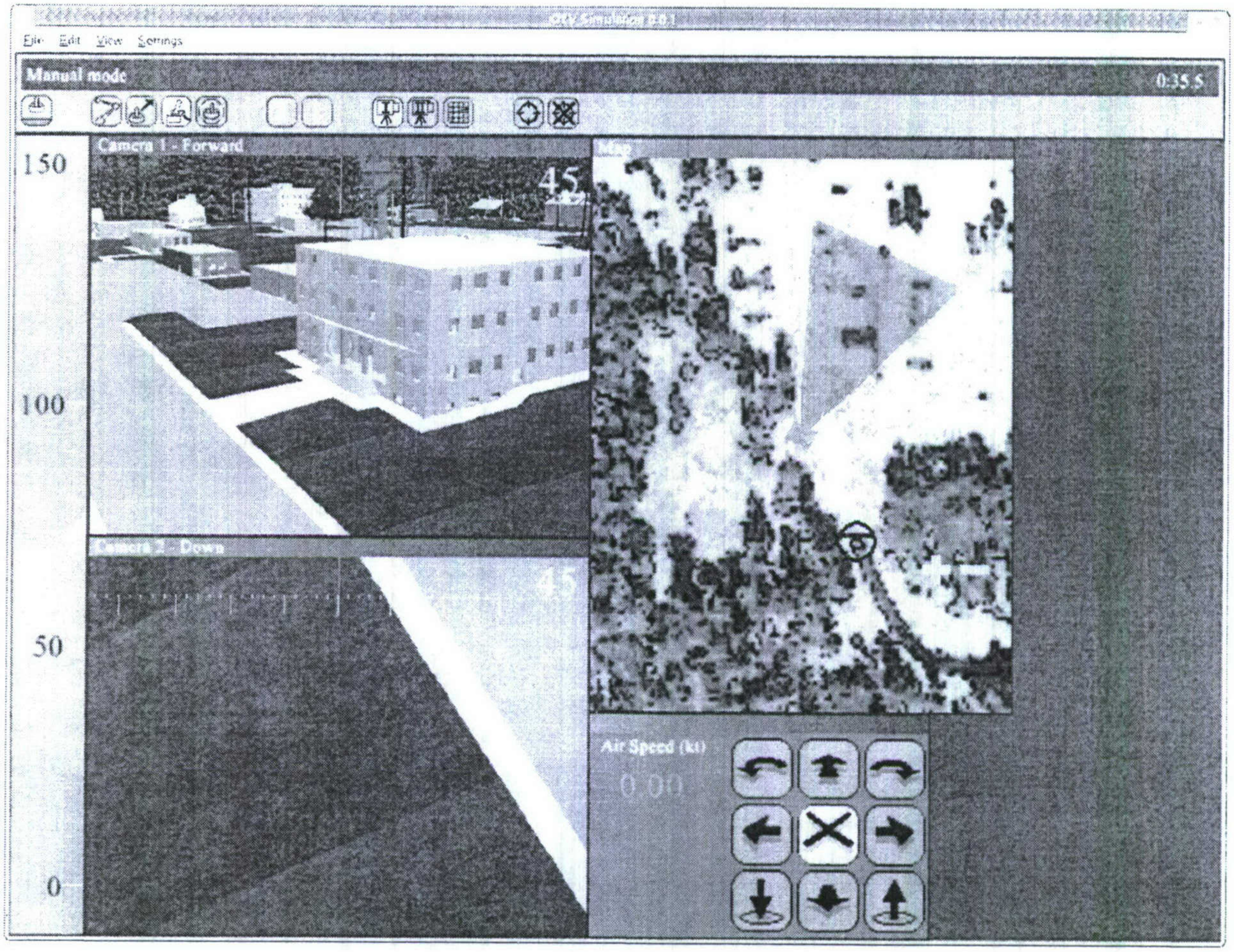


Figure B-3. OCU, two simultaneous camera views with discrete input control.

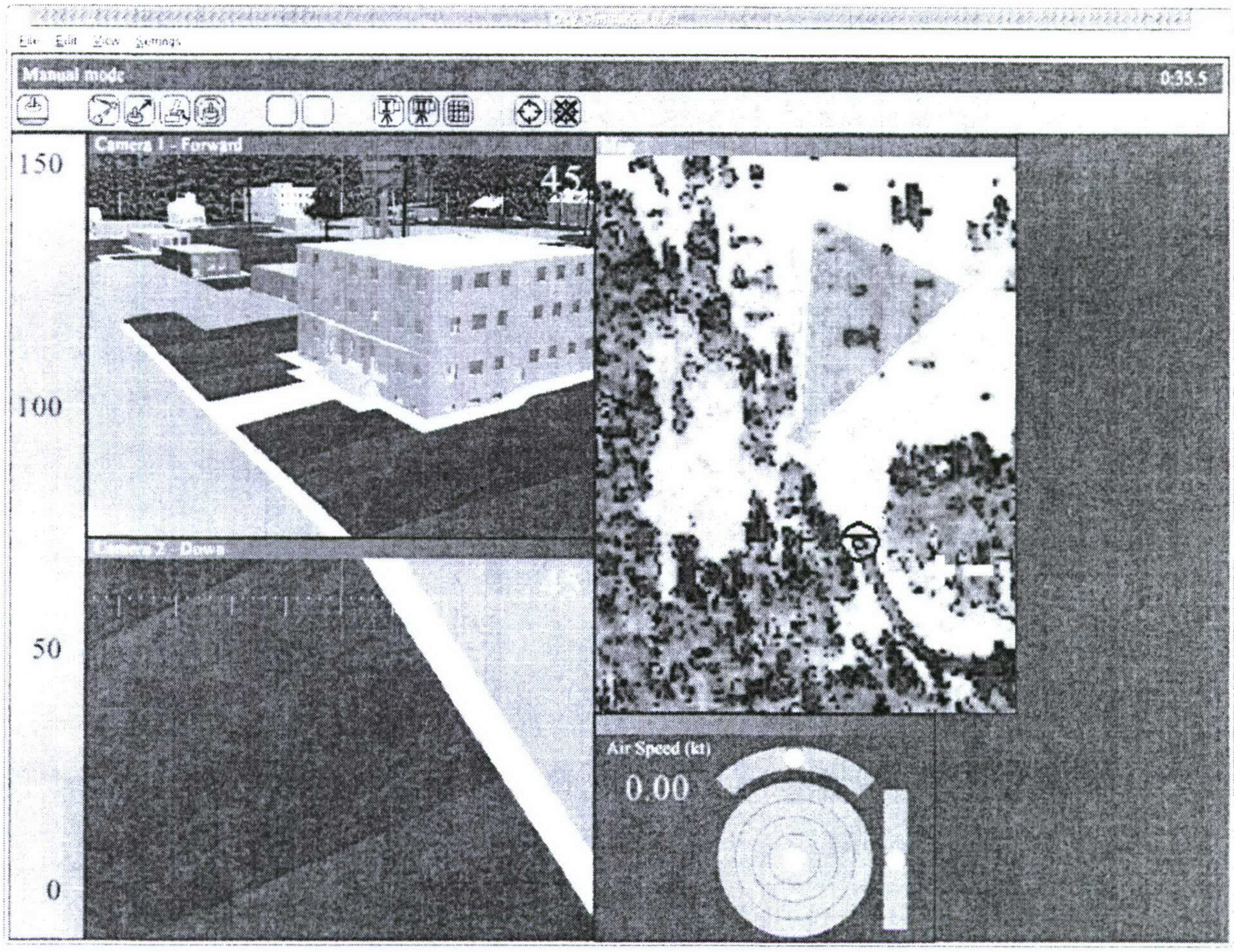


Figure B-4. OCU, two simultaneous camera views with continuous input control.

Appendix C

Participant Training Guide

A different training manual was produced for each of the eight conditions. To create these an original "baseline" guide was edited to take into account the required variations for each condition.

The following gives the training manual for participant in the game controller-discrete ICS-one camera view condition.

Army Research Institute
Intuitive Means of Robotic Control
Testbed

Participant's Guide

1camdiscreteGC

INSTITUTE for SIMULATION & TRAINING

MAV Study – IST 1

Spring/Summer 2006

(The format of this manual has been slightly modified to meet publication guidelines)

Introduction to the Micro-Unmanned Aerial Vehicle Study

The US Army is undergoing a major transformation. One element of the transformation is the introduction of a new class of military platforms known as unmanned air and ground vehicles *(called UAV's and UGV's)*. A major benefit of these unmanned vehicles is that they can perform reconnaissance missions and survey areas contaminated with radiological, chemical or biological agents without risk to human life. They can also survey the battlefield and provide real-time video feedback.

We are investigating the design of operator control systems for micro-unmanned aerial vehicles that can perform these kinds of reconnaissance missions. In addition, we are investigating operator training requirements. In this experiment you will be trained on how to fly a simulated micro-UAV (MAV) and then you will complete a set of missions that will test your ability to maneuver the MAV and locate various targets. After each mission you will be given a short questionnaire that asks you to rate certain aspects of the task you performed.

It takes approximately **90 - 120 minutes** to complete the experiment. **No previous flight experience is necessary to participate in this study.**

Confidentiality

Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in an electronic file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

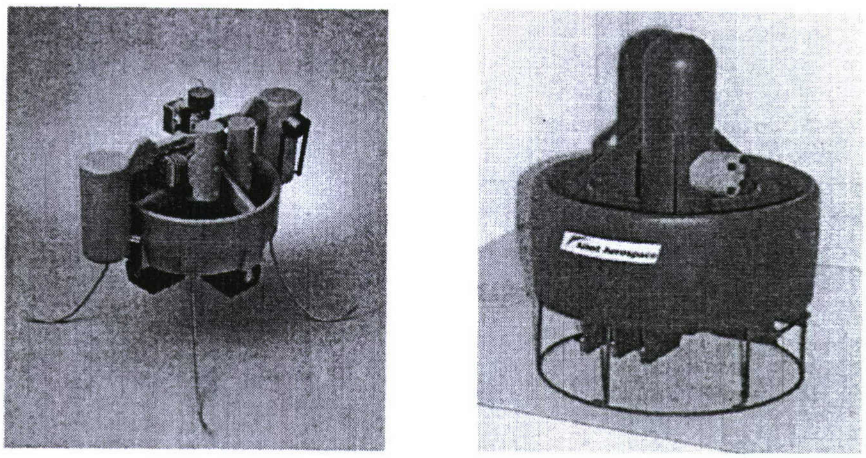
If you are prepared to participate in this experiment, please read and sign the **Consent Form and Voluntary Agreement**. Please also indicate on that form your preferred method of compensation. We offer cash payment or course credit. Also, please feel free to ask the experimenter any questions. Keep in mind that you do have the right to withdraw from this experiment at any time, for whatever reason.

When you have finished reading and signed the voluntary consent form, begin by reading the following section titled ***'Overall Description of the MAV Simulation'*** on the following page. You are not required to memorize all the information contained here, but if you have any questions on the material please feel free to ask the experimenter for clarification.

Overall Description of the MAV Simulation

You will be working with a simulation for flying a micro unmanned aerial vehicle. The micro-UAV itself will be referred to from now on as "the MAV". This is not a fixed-wing

aircraft like most airplanes are; rather it is a small rotary craft with an internal fan and duct design (see prototype photos below). An operator controls the MAV using a laptop computer equipped with an input device such as a mouse or joystick controller. This interface is referred to as the OCU – Operator Control Unit. This is a dismounted control unit, as it is envisioned that a dismounted Soldier (on foot, rather than in a vehicle) will be controlling the MAV.



MAV prototypes from Honeywell and Allied Aerospace

Introduction to the OCU and MAV Camera System

The MAV is equipped with a dual camera system. When the vehicle flies through the simulated environment you will be able to view video images sent back to the OCU. You will be instructed on how to operate the cameras as well as how to use the OCU interface and controllers to pilot the MAV. You will also have an opportunity to practice some manual flight/piloting techniques before beginning the actual experiment. After basic instruction, a training session will take place; then you will move on to the assigned pilot mission tasks where performance data will be recorded. Be sure that you understand the objective of each mission before starting a trial. The experimenter is available to answer your questions before you begin each task, so please ask for help if you are unsure of any requirements. Unless instructed otherwise, **it is important that you complete each task as quickly and efficiently as possible.**

At the end of the training session and at the end of each mission you will complete a short computer-based questionnaire. In the first section you will rate different aspects of the task you performed; then you will be asked to choose between a pair of items that relate to your performance. You must choose one and only one item for each pair. Then you will proceed to the next mission.

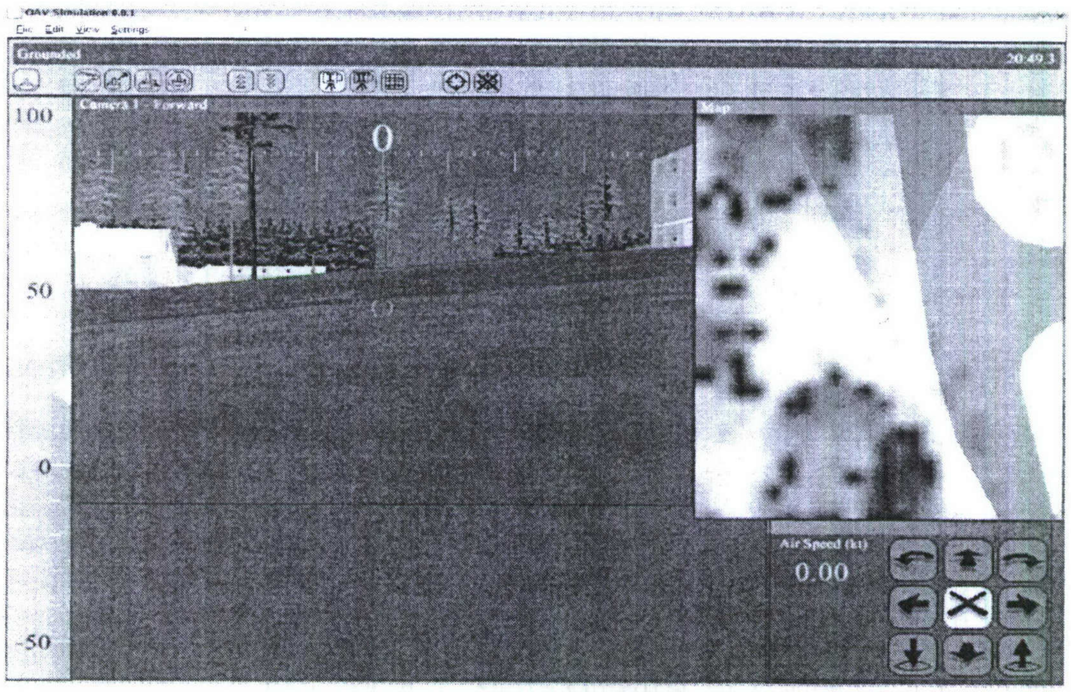
Training Session

The goal of training is to familiarize you with the flight characteristics of the MAV, and to give you an opportunity to practice piloting the MAV in manual mode. We will begin by

reviewing the features of the OCU and then proceed to a series of practice exercises. The experimenter will facilitate this training session and provide instruction on how to complete the assigned tasks.

OCU Layout and on-screen controls

Below you will see a sample layout of the OCU. On the left side of the screen is the video sensor imagery (camera views), and in the upper-right you will find an overhead map view of the terrain database. Just below the map view there is a control pad that is used for issuing flight commands to the MAV. The control pad will be examined in greater detail throughout training. There is an altimeter along the left border area of the OCU display, as well as a task bar along the top that contains various icons. You will be instructed on how to use all of the relevant gauges and icons during training.



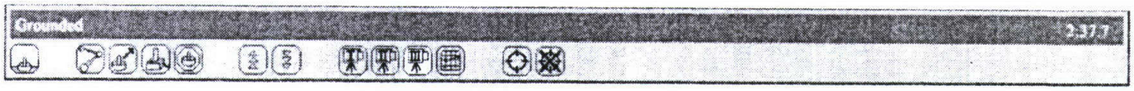
OCU with single view overlapping cameras with discrete input control pad

The experimenter will handle tasks such as loading mission files and scenarios, so you only need to focus on learning how to operate the MAV itself. Before beginning the flight training exercises, we will learn about the function of the OCU in more detail.

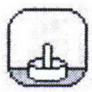
Understanding the Task Bar Icons

The **upper task bar** (below) includes the **take-off (and landing), mission mode, and camera control buttons.** There is also a mission timer located on the far right of this

task bar. For this study, you will need to know how to use the take-off icon and the camera control icons.



Take-off & Landing icon



You can **take off and land** by activating the task bar icon for take-off and landing. This is done by pressing button (10) on the joystick controller. Once the take off button is pressed the MAV will automatically climb to an altitude of approximately **60 feet above the ground level**. At this time you may pick up the joystick and execute the take-off command. You will see the red stop sign icon illuminate when you have reached take-off altitude. Pressing button 10 on the joystick will now execute the land command. You may land the MAV now.

Activating Camera Views and taking Snapshot photos

These camera buttons allow the operator to switch between the available camera images. This study uses a 2 camera setup. On the OCU, camera image #1 is the view from the MAV's forward camera and camera image #2 displays the view from the downward camera.

One of the unique features of the OCU is the ability to take snapshots with either camera. Before taking a snapshot, you will need to activate the camera that you want to take the picture. The active camera image will always have a blue border on the top of the view frame, as well as a ( ) overlay in the center of the image. The corresponding icon on the task bar will also illuminate. To change the active camera view you must use the joystick to activate the group of icons on the task bar and select the camera you want.
To activate a camera view: This is done by pressing and holding joystick button #2 while you scroll through the available camera views with the directional pad. The experimenter will demonstrate this feature now.

If not already airborne, try taking off and switching the camera view. Snapshots of targets can now be taken using the **(9)** button on the game controller/joystick.

Main Window Components:

Altimeter (See vertical bar on the left side of this page)

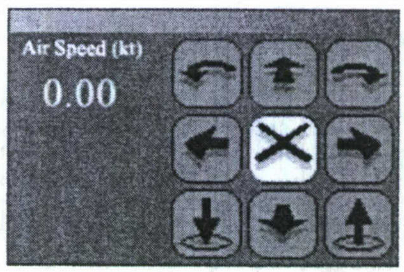
The ruler-like markings on the altimeter display the altitude of the MAV in feet above sea level. Red tabs may be visible on the upper or lower regions of the display if the experimenter has chosen to activate the altitude alarm system. The red areas simply mark the altitudes that will activate the alarm if the MAV passes into this "red zone".

< The white triangle cut-out (left) points to the current altitude of the MAV. In this case, the MAV is approximately 82 feet above sea level.

The light brown column at the lower end of the bar marks the altitude of the nearest surface below the OAV (this is the current ground level).

Note!~ In the current example, the MAV is approximately 82 feet above sea level, but the ground level is approximately 22 feet. This means the MAV is only 60 feet above ground!

<u>Manual Input Control Pad</u> (Discrete Mode):



This manual input control pad lets you control the position of the MAV manually. For this display, 9 buttons are used as the interface to the MAV. The four straight-arrow icons represent forwards, backwards, left, and right. The curved arrow icons in the upper corners show <u>rotation</u> of the MAV left and right. The lower corner icons move the MAV up and down. The middle X icon stops the MAV. Your airspeed is also shown here in knots. Max speed is 6 knots. You will issue these commands to the MAV by using the joystick. Joystick training is next.

<u>Note on Input Controller Feedback</u>

Because you are using the joystick to control the MAV, the control display will activate when an input is received. The display provides feedback in this way to the operator

that a command has been issued and is being executed. Arrow icons on the discrete control pad will illuminate when that command has been entered, i.e. when you push forward on the joystick, the forward arrow will illuminate. The brighter the icon gets, the faster you are traveling.

Joystick / Game Controller

The joystick/game controller is shown below, and by now you have at least performed some basic tasks with this device. We will now go over how to use the joystick for all of the tasks required during this experiment.

Controlling MAV movement with the Joystick:

The **left thumb stick** controls movement forward, backward, and sideways (or at angles), but the MAV heading never changes when the left thumb stick is used. Pushing up on this thumb stick moves the MAV forward. Pulling down on the stick moves the MAV backwards. Moving the stick from side to side moves the MAV right or left without altering heading.

The **right thumb stick** controls altitude and heading/rotation. Pushing up on the stick increases the MAV's altitude, and pulling down decreases altitude. Moving the right thumb stick from side to side rotates the MAV in place.

It is possible (and expected) to use both sticks simultaneously to rotate, change altitude, and move at the same time. At this time, you may take-off and practice manipulating the thumb sticks for approximately 1 -2 minutes.

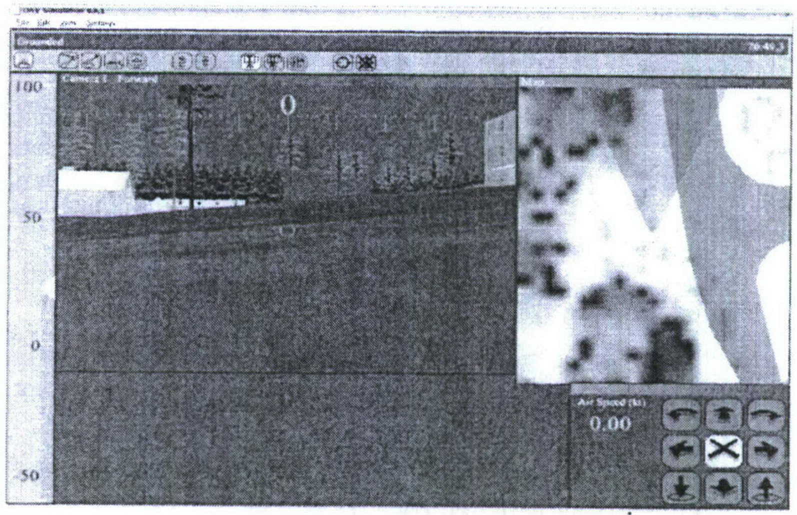
Using the Joystick to activate icons from the task bar:

The buttons on the right-hand side of the joystick (# 1 – 4) are used to highlight groups of icons on the task bar. Once a group of icons is highlighted, the directional pad of the left-hand side of the controller is used to select the individual icon you wish to activate.

To select a camera view: hold down button #2 on the controller. While holding the button, use your left thumb to press the directional pad to scroll through the different camera icons. When the camera view (marked I or II) is highlighted, release button #2 to activate the window. Note that the upper border of the active camera view window will also turn blue.

Heading Tape

Note that each camera view window has a **heading tape** located along the top edge of the frame. This number indicates the current heading (based on 360 degrees) of the vehicle with regard to that camera image. Because the cameras have been locked in place for this experiment, the participant can assume that the forward camera view heading is the same as the MAV heading. So if the heading tape reads "270" then you know the MAV is facing due west.



0-degrees is the same as due North on a regular compass. 90-degrees = East; 180-degrees = South; 270-degrees = West.

Important Note!! ~ The downward camera view is locked at 90 degrees from horizontal (this is essentially straight down). However, when the MAV is in motion the vehicle tilts in a similar manner to a moving helicopter. This tilting will cause the downward camera to point slightly backwards, thus giving the operator a heading reading that is opposite of the forward camera view. **i.e. if the forward camera heading is 0-degrees, then the downward camera heading will read 180-degrees <u>only while the MAV is in motion</u>.**

Practice Time: Now that you have learned all the functions of the OCU and the flight controls, we will complete a series of practice exercises beginning on the next page.

Practice Exercises

These exercises will give you a chance to practice the various tasks required to complete the missions in this study.

Warm up

Start this warm up session by executing a take-off and briefly practicing the following maneuvers. You will notice that inertia comes into play when trying to stop the MAV, so you will need to learn to estimate things like stopping distances and rotational velocity carry-over.

1) Move the right thumb stick up and down to make the MAV ascend and descend.
2) Move the right thumb stick side to side to rotate the MAV.
3) Move the left thumb stick up and down to make the MAV fly forward and backwards.
4) Move the left thumb stick side to side to move the MAV laterally. Note that the heading only changes when you rotate the MAV with the right thumb stick.
5) Activate camera 1 and then activate camera 2. Now switch back to camera 1 and take a snapshot.
6) Land the MAV.

Next you will complete a series of timed practice exercises. The experimenter will observe these exercises and determine if you have met the time requirement before allowing you to proceed to the next exercise. All mission and properties files needed for these exercises will be loaded by the experimenter.

Practice Exercise 1

1) Press OK (button 10) to start the simulation and timer.
2) Execute the **Take-off** command.
3) When the Red Stop icon illuminates, execute the **Land** command.
4) This exercise must be completed in 30 seconds (:30) or less.

Practice Exercise 2

9) Press OK to start the simulation and timer
10) Execute the **Take-off** command.
11) At or before the completion of take-off, activate the view window for Camera 1 (forward view).
12) Take a snapshot with camera 1.
13) Activate the view window for camera 2 (down view).
14) Take a snapshot with camera 2.
15) Execute the **Land** command.
16) This must be completed in 40 seconds (:40) or less.

Practice Exercise 3 (with alarm active)

1) The upper altitude alarm will be set at 150 feet and activated.
2) Press Ok to start the simulation and timer.
3) Execute the **Take-off** command.
4) Ascend to 150 feet and trigger the alarm.
5) Immediately descend to 50 feet or below without hitting the ground.
6) Ascend back up to 100 feet but less than 150 feet.
7) Rotate the MAV 360-degrees without dropping below 100 feet. It is required that the heading tape shows the number "0" after completing 1 rotation with the MAV. The "0" must remain in the forward camera view window before landing.
8) Execute the **Land** command.
9) This exercise must be completed in 1 minute 35 seconds (1:35) or less.

Practice Exercise 4: rapid command execution

For this exercise you will follow a series of oral commands issued by the experimenter. After take-off and as soon as the Red Stop icon illuminates, you will immediately begin to hear a series of flight commands. Commands will be given as fast as you can correctly comply. Once the correct feedback is observed from the OCU the experimenter will proceed to the next command.

Note: it is not important that the MAV travels any considerable distance. The purpose of this exercise is to allow you to learn the mapping of all buttons and icons and their corresponding functions. The experimenter is looking mainly for the correct feedback from the OCU control pad located in the lower right of the display.

Rapid command execution - Part A

1) Press OK to start the simulation and timer.
2) Execute Take-off.
3) The first series of commands after take-off will be: ***9 commands.***
4) This exercise must be completed in 1 minute 5 seconds (1:05) or less.

The experimenter will now reload the properties file and reset the timer.

Rapid command execution - Part B

5) Press OK to start the simulation and timer.
6) Execute take-off.
7) The second series of commands after take-off should be: ***14 commands.***
8) This exercise must be completed in 1 minute 25 seconds (1:25) or less.

The next 2 exercises involve flying the MAV over longer distances and following pre-determined mission parameters. These will be similar to the missions you will complete during the remainder of the experiment.

Practice Exercise 5

In this exercise you will pilot the MAV around the main roadway that forms an oval inside the terrain database. Waypoints will be visible in the overhead map view window. Waypoints are used to determine the correct flight path of the MAV. The experimenter will explain this to you in more detail while the MAV completes the mission autonomously.

1) The experimenter will load and run this mission autonomously and will point out the Landing Zone (LZ) on the (H) building.
2) After the autonomous mission finishes, the simulation will be reset.
3) You must now manually pilot the MAV around the gray pathway while remaining to the left of the 4 red poles and landing in the correct LZ.
4) When ready, press OK to start the timer.
5) Execute the **Take-off** command.
6) Complete one lap around the 4 red poles and stay over the gray path.
7) Land on the (H) building.
8) This exercise must be completed in 3 minutes 50 seconds (3:50) or less.

Practice Exercise 6 – obstacle course

In this exercise you have obstacles to navigate. You will also take 2 snapshots at the end of the run. Complete the mission by flying through the series of red and green poles and then return to your start point to take the snapshots.

1) The experimenter will load and run this mission autonomously with waypoints visible. Observe how the MAV passes to the right of all green poles and to the left of all red poles.
2) At the end of the run, you will see the C2 vehicle parked on the sidewalk. (This is you! You control the MAV from this position inside the vehicle.)
3) You must now complete the course manually with a few additional instructions: **After you finish navigating around the poles you will need to take snapshots of the C2V with both cameras.**
4) When ready, press OK and then execute Take-off.
5) Complete the obstacle course.
6) Take snapshot from camera 1
7) Take snapshot from camera 2.
8) Land – but do NOT land on the C2 vehicle!
9) This exercise must be completed in 5 minutes (5:00) or less.

You will now complete a short computer-based questionnaire. The experimenter will explain this and give you instructions at this time. Then you will begin a series of 6 missions.

Mission Protocol for ARI/IST MAV Experiment 1

There will be 6 missions for you to complete during this portion of the study. The experimenter will instruct you on mission requirements and provide any documentation necessary. If you are unsure of any of these requirements please ask for clarification. Once you begin a mission, the experimenter will have very limited interaction with you. He/she will not be able to answer questions on mission requirements once you execute the take-off command, so please ask beforehand.

Mission 1

This mission is a repeat of practice exercise #5 where you piloted the MAV around the gray pathway while remaining to the left of the 4 red poles.

1) You will manually pilot the MAV around the gray pathway while remaining to the left of the 4 red poles and landing on the (H) building.
2) When ready, press OK to start the timer.
3) Execute the **Take-off** command.
4) Complete one lap around the 4 red poles and stay over the gray path.
5) Land on the (H) building.

Complete the computer-based questionnaire at this time and then proceed to Mission 2.

Mission 2

This mission involves using the MAV to do reconnaissance work. You will get a handout titled "Mission 2 Intel & Recon". Review this with the experimenter and then complete the required tasks. The experimenter may ask you for situational updates at different points during this mission.

1) Read the "Mission 2 Intel & Recon" handout.
2) When ready the experimenter will load the mission scenarios.
3) Press OK to start the mission timer.
4) Execute Take-off.
5) Locate the church.
6) Use the MAV to observe the church from all sides.
7) Determine who or what is occupying the church.
8) Pilot the MAV to the landing zone.
9) Complete the debriefing with the experimenter.

Mission 3

This mission repeats practice exercise #6 where you navigated a series of red and green poles. You will also take 2 snapshots of the C2 vehicle at the end of the run.

Complete the mission by flying through the series of red and green poles and then return to your start point to take the snapshots of the C2V.

1) You must complete the obstacle course manually.
2) After you finish navigating around the poles you will need to take snapshots of the C2V with both cameras.
3) When ready, press OK and then execute Take-off.
4) Complete the obstacle course.
5) Take snapshot of the C2V with camera 1
6) Take snapshot of the C2V with camera 2.
7) Land – <u>but do NOT land on the C2 vehicle!</u>

Complete the computer questionnaire at this time and then proceed to Mission 4.

<u>Mission 4</u>

This mission involves using the MAV to do more reconnaissance work. You will get a handout titled "Mission 4 Intel & Recon". Review this with the experimenter and then complete the required tasks. This is primarily a target identification mission. Once again, the experimenter may ask you for situational updates during this mission.

1) Review the "Mission 4 Intel & Recon" handout.
2) The experimenter will load the mission files and scenario.
3) You will have a limited time to identify as many targets as possible within the terrain database.
4) Positive ID can only be achieved by taking snapshots of each entity with <u>both the forward and down cameras</u>, and each entity must be centered in the frame so that the center ( ) overlay is touching part of the entity.
5) When ready, press OK to begin the mission and start the timer.
6) Immediately begin looking for entities to identify via the camera.
7) The experimenter will tell you to stop when time has expired.

Complete the computer-based questionnaire at this time.

<u>Mission 5:</u> Repeat mission 1 – This is your final attempt to make the best time possible. (Then complete the computer-based questionnaire.)

<u>Mission 6:</u> Repeat mission 3 – This is your final attempt to make the best time possible. ***When finished you may proceed to your final debriefing session.***

Appendix D

Demographics Questionnaire

1. Participant Number	

2. Today's Date	

3. Year of Birth	

4. Gender	○	Male	○	Female

5. Have you graduated from High School?	○	Yes	○	No

6. Current Education Level	
Grade school or less	○
High School graduate	○
Some college	○
College graduate	○
Graduate degree	○

7. Is your vision correctable to 20/20?	○	Yes	○	No

8. To your knowledge are you color blind?	○	Yes	○	No

9. How often do you use a computer?	
Daily	○
A few times per week	○
A few times per year	○
Not in the past year	○
Never	○

10. Estimate how many hours per day you use a computer on average.	
0	○
1	○
2	○
3	○
4	○
5	○
6	○
7	○
8	○
More than 8 hours per day	○

11. How would you rate your computer skills?	
Novice/Beginner	○
Intermediate	○
Expert	○

12. Which of the following computer input devices have you used more than once?		
□ Keyboard	□ Standard mouse	□ Touch pad mouse
□ Touch screen	□ Roller-track ball	□ Joystick
□ Dual thumb-stick game controller		

13. Select any of the following game consoles that you either own or have used on a regular basis.		
□ Microsoft XBOX	□ Sony Playstation	□ Sony Playstation 2
□ XBOX 360	□ Sega Dreamcast	□ Nintendo Gamecube
□ Super Nintendo	□ PC game system	

14. How would you rate your video game skills?	
Novice/Beginner	○
Intermediate	○
Expert	○

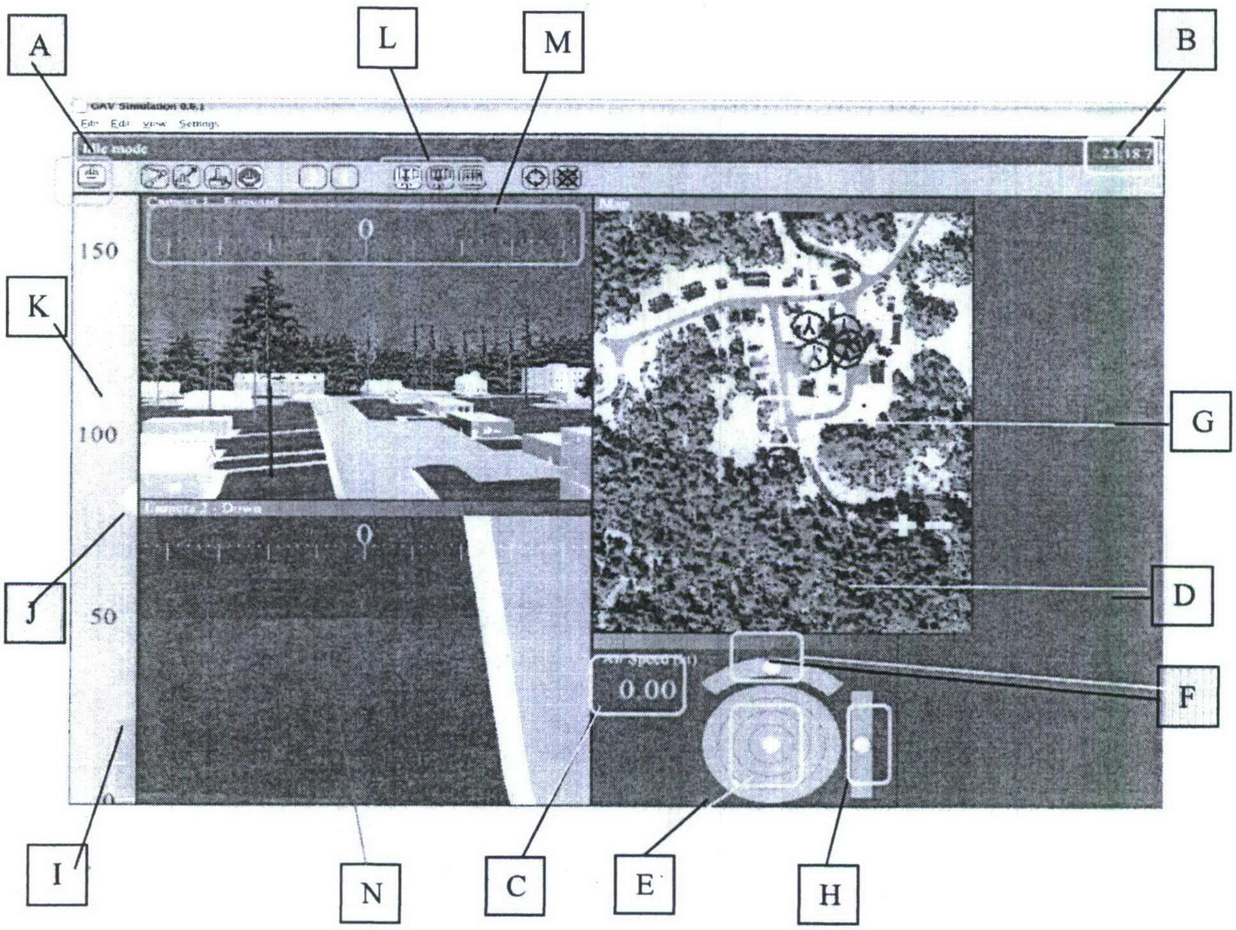
15. How many days in the past week have you played video games?	
0	○
1	○
2	○
3	○
4	○
5	○
6	○
7	○

16. Estimate how many hours per day you play video games on average.	
0	○
1	○
2	○
3	○
4	○
5	○
6	○
7	○
8	○
More than 8 hours per day	○

17. Mark the selection that best describes which hand you use for each task.					
	Always left	Usually left	No preference	Usually right	Always right
Writing	○	○	○	○	○
Drawing	○	○	○	○	○
Throwing	○	○	○	○	○
Scissors	○	○	○	○	○
Toothbrush	○	○	○	○	○
Knife (without fork)	○	○	○	○	○
Spoon	○	○	○	○	○
Broom (upper hand)	○	○	○	○	○
Striking match (match)	○	○	○	○	○
Opening box (lid)	○	○	○	○	○

Appendix E

MAV Training Evaluation Worksheet – ARI/IST1 OCU



To ensure that you have a basic grasp of the MAV pilot interface and the available flight commands, please complete the following exercise.

Each of the critical features of the user interface are labeled above with letters A – N. Every letter must be used, so choose the best answer. Enter the corresponding letter in the blank following each of the item descriptions below:

Altimeter	______	Camera Selection Icons	______
Mission Timer	______	Vertical Velocity Control	______
Rotational Velocity Control	______	Take-off & Land Icon	______
Heading Tape	______	Horizontal Velocity Control	______
Satellite MAP View	______	MAV Location on Map	______
Current MAV Altitude	______	Ground Level Indicator	______
Camera 2 Image	______	Air Speed Indicator	______

Appendix F

MAV USABILITY QUESTIONNAIRE (IMROC-OCU EXP: 1 Joystick)

Circle the number that best describes your reaction between the 2 extremes given.

1) The system I worked with was

wonderful									terrible
1	2	3	4	5	6	7	8	9	10

2) The system I worked with was

easy									difficult
1	2	3	4	5	6	7	8	9	10

3) I found this experience

satisfying									frustrating
1	2	3	4	5	6	7	8	9	10

4) The system I worked with seemed

Capable of doing the exercises									Unable to do the exercises
1	2	3	4	5	6	7	8	9	10

5) I found this experience

stimulating									dull
1	2	3	4	5	6	7	8	9	10

6) The system I worked with was

flexible									rigid
1	2	3	4	5	6	7	8	9	10

7) The functions of the on-screen manual control buttons (on the control pad) were

clear									confusing
1	2	3	4	5	6	7	8	9	10

8) The functionality of the buttons for switching between camera views was

clear									confusing
1	2	3	4	5	6	7	8	9	10

9) Organization of information on the video display screen was

clear									confusing
1	2	3	4	5	6	7	8	9	10

10) Current status (such as Taking off, Landing, Grounded) messages were

adequate									inadequate
1	2	3	4	5	6	7	8	9	10

11) When controlling the MAV in flight using the joystick, the device was

easy to use									difficult to use
1	2	3	4	5	6	7	8	9	10

12) As I progressed through the missions using the joystick, my hands and/or wrists became fatigued

Never									Always
1	2	3	4	5	6	7	8	9	10

13) When using the joystick to enter flight commands to the MAV, maintaining awareness of individual mission objectives was

easy									difficult
1	2	3	4	5	6	7	8	9	10

14) When using the LEFT thumb stick (forward, back, left & right movements) to move the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

15) Using the RIGHT thumb stick (up, down & rotation) to move the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

16) When using the joystick to stop the motion of the air vehicle while in manual control, the air vehicle reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

17) When using the joystick to switch between camera views (highlighting the camera icon located on the task bar), the display reacted as I expected.

always									never
1	2	3	4	5	6	7	8	9	10

18) While using the camera to take snapshots of targets, centering the target so it was aligned with the ( ) overlay was

easy									difficult
1	2	3	4	5	6	7	8	9	10

19) When piloting the MAV in manual control, determining the current heading of the MAV from the 360-degree directional heading tape was

clear									confusing
1	2	3	4	5	6	7	8	9	10

20) It was clear when the air vehicle had landed

always									never
1	2	3	4	5	6	7	8	9	10

21) The system provided adequate feedback when I issued a command to the MAV.

always									never
1	2	3	4	5	6	7	8	9	10

22) The OCU interface keeps you informed about what it is happening

always									never
1	2	3	4	5	6	7	8	9	10

23) Learning to operate the system was

easy									difficult
1	2	3	4	5	6	7	8	9	10

24) Remembering names and use of commands was

easy									difficult
1	2	3	4	5	6	7	8	9	10

25) Tasks could be performed in a straightforward manner

always									never
1	2	3	4	5	6	7	8	9	10

26) Training materials were

clear									confusing
1	2	3	4	5	6	7	8	9	10

27) After this training, I am ready use this system to fly a real air vehicle

very confident									not at all confident
1	2	3	4	5	6	7	8	9	10

28) The system speed was

fast enough									too slow
1	2	3	4	5	6	7	8	9	10

29) System reliability was

reliable									unreliable
1	2	3	4	5	6	7	8	9	10

30) Correcting your mistakes was

easy									difficult
1	2	3	4	5	6	7	8	9	10

31) Both experienced and inexperienced users' needs were taken into consideration

always									never
1	2	3	4	5	6	7	8	9	10

32) Do you have any previous Remote Control R/C experience? YES / NO (circle one)

If you answered **yes**, please briefly describe:

____

____.